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THE AERIAL EFFECT IN RECEIVING SETS WITH LOOP AERIAL

by P. CORNELIUS.

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A loop aerial can be used to advantage with portable radio sets because it is less sensitive to local interferences than a mains aerial or a movable capacitative aerial. By making use of the directional effect of the loop it is also possible in certain cases to diminish the interference by undesired transmitters. The condition for the satisfactory functioning of the loop in both cases is that the aerial effect should be kept small, a condition which requires special precautions when the receiver is supplied from the mains. Several methods of combatting the aerial effect are discussed in this article. One of these methods is the use of a loop of only one winding. This method is applied in the Philips receiving set type 902 A (superheterodyne receiver with a stage of high-frequency amplification).

In a previous article [1]) it was explained that a well-constructed loop aerial is the most suitable aerial for portable receiving sets with mains connection, and that the reason for this lies in the lower sensitivity to local interferences of the loop aerial compared with a capacitative aerial. In this article a study will be made of the problems which occur in practical cases when advantage is taken of these favourable properties of the loop aerial. In conclusion a receiving set will be described which is equipped with a loop aerial consisting of only one winding.

The reason why the behaviour of a loop aerial is favourable with respect to local interferences is briefly summarized in the following. If a station is being received which is a great distance away compared with the wave length, so that the receiving aerial is situated in the so-called radiation field of the transmitter, the intensities of the alternating electric and magnetic fields at the aerial are in a definite ratio to each other, namely the electric field strength F in V/m is a factor $120\,\pi$ larger than the magnetic field strength H in A/m. Now since a capacitative aerial reacts to the electrical component of the field, while the signal voltage is generated in the loop by the magnetic component, it is clear that a local source of interference will only have the same disturbing effect for these two types of aerials when the electric and the magnetic field strengths of the interference are also in the ratio $F/H = 120\,\pi$. It is now found, however, at least in the wavelength region above 200 m, that the ratio F/H is usually much greater than $120\,\pi$ for the local sources of interference, so that a capacitative aerial will receive relatively much more of the local interference than a loop.

The aerial effect

It is obvious that the advantage of the loop just described will only be fully realized when the loop does actually react only to the magnetic field, *i.e.* when no voltage or current is induced between the terminals of the loop by an alternating electric field whose magnetic component is negligibly small [2]). In general a loop will not satisfy this condition exactly, and the loop is then said to exhibit the "aerial effect".

The presence of the aerial effect can easily be demonstrated by comparing the directional action of different loop aerials which are situated in the radiation field of a transmitter. In the case of an electromagnetic wave which is propagated along a well conducting horizontal earth's surface in the open, the vector of the electric field is vertical, while the magnetic field is horizontal. At the same time both are perpendicular to the direction of propagation.

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[1]) See Philips techn. Rev. **6**, 302, 1941.

[2]) For the present we confine ourselves to frequencies at which the wavelengths are still long compared with the dimensions of the aerials considered. If this limitation is omitted a pure electric field (without magnetic field) cannot exist.

Now a loop is sensitive only to that component of the magnetic field which is perpendicular to the plane of the loop. This component disappears when the normal to the plane of the loop is directed towards the transmitter. Thus when the loop is turned about a vertical axis the direction diagram of *fig. 1* holds for the voltage excited in the loop by the magnetic field. This diagram is expressed by the formula

$$V_a = V_0 \sin \alpha, \quad \ldots \ldots \ldots \ldots \quad (1)$$

where α is the angle between the normal to the plane of the aerial and the direction of propagation. It is obvious that the maxima are flat and the minima sharp.

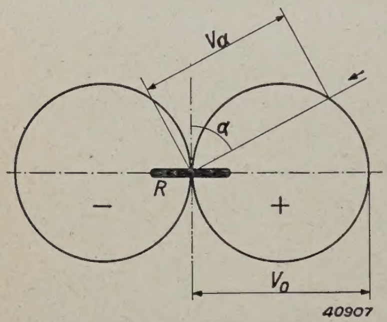

Fig. 1. Directional effect of the loop. The radius V_a indicates the amplitude of the voltage induced by the magnetic field of a wave in the direction of the arrow.

If a loop has an aerial effect a second term must be added to the right-hand side of equation (1), which term is independent of α and in general makes the minima much less sharp. The fact that the contribution of the electric field to the voltage on the loop is indeed independent of α follows immediately from the fact that the electric field has a vertical direction, so that the relative position of the loop with respect to the electric field does not change upon rotation about a vertical axis [3]).

The aerial effect is not only undesirable because of its effect on the sensitivity to local interferences, but also because, as we have seen, it makes the directional effect of the loop less sharp. The directional effect may be used to advantage in many cases to improve the selection between two transmitters operating on the same or almost the same wavelength: the undesired transmitter is simply "turned out". By this means, for instance, side-band interference can be suppressed without the necessity of lowering the quality of the reproduction by cutting off the high tones, as would be the case in reception with a capacitative aerial [4]).

Finally it is found, as will be discussed below, that the aerial effect is accompanied by a greater sensitivity to interferences which can be transmitted to the set *via* the power mains. Therefore for the sake of avoiding also this type of interference it is important to prevent the aerial effect. In this article we shall study the way in which the aerial effect occurs and the available means of combatting it. We shall then pass on to a description of a receiving set with a loop aerial developed by Philips in which special attention has been paid to the countering of the aerial effect.

The causes of the aerial effect

A loop aerial is a continuous conductor which connects the input terminals of the receiving set with each other. Thus with constant or slowly varying electric fields in space no potential difference is in general to be expected between the input terminals. In the case of high-frequency variations of the field strength, however, voltages may occur. In order to obtain a better insight into this phenomenon we shall go somewhat deeper into the behaviour of a conductor in an electric field.

If an originally uncharged conductor is brought into a constant electric field, there occurs in the conductor a separation of equal numbers of positive and negative charges which distribute themselves on the surface of the conductor in such a way that the electric field strength becomes zero in the conductor. We must therefore picture the separation of the charges in such a way that in the originally electrically neutral conductor a certain amount of negative electricity is transferred from one part to another, so that in the first part the corresponding amount of positive electricity remains in excess.

The amount of electricity transferred is proportional to the original electric field strength and further depends upon the form of the conductor and of its surroundings. As the simplest example, the charge distribution on a vertical rod situated in a vertical electric field of strength

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[3]) In addition to the aerial effect there may be other causes which may spoil the directional effect. Such causes are: night effect, elliptical polarization of the radiation or the formation of rotating fields by short-circuited loops in the vicinity of the loop aerial. These causes have no connection with the nature of the aerial and will therefore not be considered in this paper.

[4]) It is obvious that this method of removing interference is only possible when the directions from the loop aerial towards the desired transmitter and towards the undesired transmitter (or source of interference) make a large enough angle with each other.

F is given in *fig. 2a*. If the field is directed upwards, positive charge is concentrated at the upper end and negative at the lower end. In the middle of the rod is a neutral zone where the transition from the negative to the positive surface charge takes place.

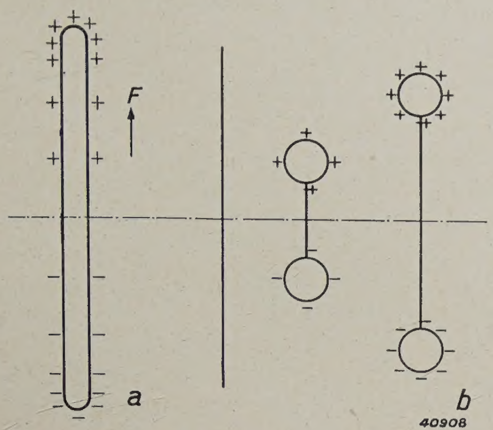


Fig. 2. *a*) Charge distribution on a rod situated in a homogeneous constant electric field F.
b) The same for an aerial consisting of two spheres connected by a wire. With a given value of the field strength the density of charge on the spheres increases with their distance apart.

The farther a surface element of the rod is from the neutral zone, the larger the amount of electricity which will be accumulated in this surface element with a given value of the field strength originally present. The density of charge at the top of a rod of a given thickness at a given field strength therefore becomes larger the longer the rod. Such a conclusion may also be drawn for other forms of aerials. If, for example, a vertical aerial consisting of two spheres joined by a vertical wire (fig. 2*b*) is considered, the charge which the spheres assume in a constant electric field will be larger the farther the two spheres are apart.

From the distribution of charge on a conductor in a homogeneous constant electric field, we may now draw conclusions about the behaviour of a conductor in an alternating field. By an up and down motion of the electric charge the conductor will try to keep the internal field always equal to zero. When the changes of the external field do not take place too rapidly, so that the corresponding wavelength is still large compared with the dimensions of the aerial system, it may be expected that the internal field will actualy be eliminated at every moment, at least when the inductive and ohmic voltage drop in the conductor with the currents resulting from the upward and downward motion of the charges are sufficiently small compared with the voltage which is compensated by the displacement of charge. In the case of the aerials customarily used for intermediate and long waves it may be assumed that this condition is fulfilled.

The charge distribution on an aerial in an alternating field is therefore similar at every moment to that in a constant field which has the same value at the moment considered. Due to the change in the charge with time we obtain an alternating current whose amplitude changes from point to point along the conductor. The largest current amplitude occurs in the neutral zone, since of course the whole negative charge situated on one side of the neutral zone must flow through this zone. Toward the ends of the rod (fig. 2*a*) the current becomes smaller and smaller; at the very ends it is zero. An analogous result is also found for other forms of aerial, for instance fig. 2*b*.

If we now pass on to the loop aerial, which in its simplest form can be represented by a closed loop in space, we obtain for a constant electric field a charge distribution such as that represented in *fig. 3*. The positive and negative charge in this case is mainly concentrated in points *1* and *2* respectively, while points *3* and *4* lie on the neutral plane. If we again consider a varying field strength we can again draw conclusions about the currents flowing in the loop from the change in the charge distribution in the branches.

In principle the current distribution in a loop cannot be completely deduced from the picture of the charges. Even though we know how much electricity must come to a certain spot on the conductor, the path along which it must come is not yet determined. Thus in principle a negative charge in the neighbourhood of point *2* could reach its goal *via* point *3* as well as point *4*. Nevertheless, in the case in question for reasons of symmetry it may be concluded that the same currents will flow at points *3* and *4*, while points *1* and *2* are without current.

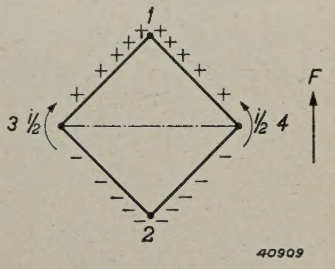


Fig. 3. Charge distribution on a short-circuited loop due to the field strength F. The arrows along the loop indicate the currents which flow in the loop when the field strength increases.

If an indicating instrument is placed in the loop which can be slid along its circumference, the largest current will be measured at points *3* and *4* and the current at points *1* and *2* will be zero. If the loop is cut open at point *3* or *4* there will be a voltage across the open ends, while this would not be the case if it were cut open at *1* or *2*.

The occurrence of the voltage may be pictured as follows. As was already mentioned, the charge distribution is given at every moment by the external field, but the currents which flow as a result of the change in this charge distribution may flow in different ways in the closed loop. From a given current configuration such as that of fig. 3, another possible current configuration can be derived, by adding a current which has the same intensity at all points along the closed loop and thus does not change the charge at any point, because at every point the same amount flows to the point as away from it. This extra current may then change with the time in any way desired.

If it is now desired to describe the current configuration which occurs when the loop is broken at a given spot, the extra current must so be chosen that it compensates the originally occurring charging current at the spot where the loop is broken. The voltage at that spot then becomes equal to the product of the extra current and the impedance of the loop.

It may therefore be said that upon any given connection of the indication instrument a loop will in general exhibit aerial effect; only with certain methods of connection is this aerial effect absent.

The effect which we are considering here is relatively small for long and intermediate waves. It may become somewhat larger when there is a mass of metal in the neighbourhood of the loop, for instance the chassis of a receiving set. The charge which flows up and down in the loop may then become larger; the position of the points on the loop where the aerial effect is absent may also be shifted. Large effects are not, however, to be expected. If, therefore, an arrangement is chosen for which the loop aerial can be represented by a loop standing free in space, or, if necessary, even in the neighbourhood of a mass of metal, and even with any arbitrary connection of the set with the loop, little difficulty will be experienced from aerial effect.

The arrangement mentioned is realized in non-earthed receiving sets with battery supply; in the case of these sets the aerial effect is indeed found to be so insignificant that it exerts no disturbing effect on the directional action and the sensitivity to interference of the loop.

The situation becomes quite different, however, when receivers with mains connections are used. In this case the chassis is connected with earth for high-frequency currents *via* the capacity of the mains transformer through the mains connection. The loop replaces the tuning coil of the first circuit and in ordinary receivers is therefore connected at one end with the chassis, while the other end delivers the voltage received to the control grid of the first valve. In these connections the loop aerial can be represented schematically by a loop situated relatively far above the earth with one end connected to earth (see *fig. 4*).

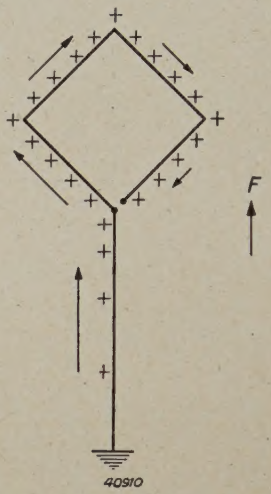


Fig. 4. Charge distribution on a loop earthed at one end due to the field *F*. The arrows indicate the currents which flow when the field strength increases. The currents are largest in the vertical earth connection and decrease gradually along the winding of the loop. The current is zero at the open end.

If we again consider the action of an electric field it is found that much greater displacements of charge must be expected than in the case represented by fig. 3. The type of aerial now exhibits certain similarity to that of fig. 2*b*, and, as in fig. 2*b*, we may conclude that the density of charge at the top will increase with increasing distance between the top and the neutral zone — in our case therefore with the height of the loop above earth. Thus it is no longer only the size of the loop but also its height above the earth which determines the electric charge of the loop in an electric field of a given strength. The magnetic receiving capacity on the other hand is independent of this height. It is thus clear that the aerial effect of a loop earthed at one end is affected by a quantity which has no connection at all with the magnetic receiving capacity, so that it may not immediately be concluded that the aerial effect is small compared with the signal received by magnetic induction.

There is still, however, a second reason why the loop earthed at one end exhibits much more aerial effect than the "floating" loop. As already stated, the charge Q_A, which in the case of the loop earthed at one end is drawn out of earth by an electric field, is in general much larger than the charge Q_Z, which is accumulated on one side of the neutral zone of the floating loop under the influence of the same field. If we consider a floating loop and a loop earthed at one end, both with the same number of windings, then the same is true for the charges q_A and q_Z per winding.

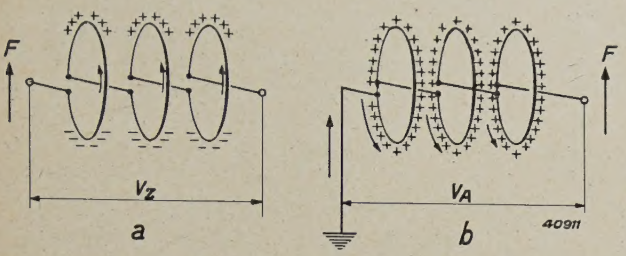


Fig. 5. Charge distribution *a*) on a floating loop, *b*) on a loop earthed at one end, due to the field *F*. The arrows indicate the local amplitudes of the currents which occur when *F* is an alternating field. In the case of the floating loop the charging current of each winding flows through that winding; in the case of the loop earthed at one end the charging current of the whole loop flows through the first winding.

In *figs. 5a* and *b* the current configurations are now given as occur in the case of the floating loop and the loop earthed at one end respectively. In the case of the floating loop the current in each winding is determined only by the charge on this winding itself: the current is equal to zero at the points indicated by dots, and at the diametrically opposite spots it has its largest amplitude ωq_Z. In the case of the loop earthed at one end, on the other hand, not only the current necessary to charge the first winding flows through this winding, but also the current which charges the following windings. If the aerial has n windings the current at the earthed side of the aerial has an amplitude of $n\omega q_A$; towards the open end of the aerial the amplitude gradually falls to zero.

The average strength of the charging current along the windings may be set equal to half the maximum strength, not only in the case of the floating loop but also in that of the loop earthed at one end. Thus for this average amplitude the following is valid :

$$I_Z = {}^1/_2\, \omega q_Z ,$$
$$I_A = {}^1/_2\, n\omega q_A .$$

The voltage amplitude of the aerial effect is equal to this average current amplitude multiplied by the impedance ωL of the loop. We thus find that:

$$\left.\begin{aligned} V_Z &= {}^1/_2\, \omega^2 L q_Z \ldots \\ V_A &= {}^1/_2\, n\omega^2 L q_A \ldots \end{aligned}\right\} \ldots\ldots \quad (2)$$

The difference between the aerial-effect voltage V_A of the loop earthed at one end and the voltage V_Z of the floating loop thus consists not only in the fact that q_A is larger than q_Z, but also that V_A is proportional to the number of windings n, and V_Z is not. The larger the number of windings, therefore, the more important the difference between the floating loop and the loop earthed at one end.

A further conclusion from equation (2) concerns the dependence on frequency. Since q_Z and q_A are proportional to F, it is clear that the voltage caused by the aerial effect is proportional to the electrical field strength and to the square of the frequency. The voltage induced by the magnetic field, however, as is of course well known, increases only with the first power of the frequency at a given value of H. From this it follows that with a given ratio of F to H the aerial effect increases proportional to the frequency.

Finally we should like to draw still another conclusion about the sensitivity of a receiving set with loop aerial to interferences from the mains. As may be seen from equation (2), the interference voltage V need not be the result of an electric field in space, but it may be caused by any phenomenon whereby an alternating electric charge q is induced on the loop. Such a phenomenon is also caused by the high-frequency interference voltages of the power mains.

We have shown that in practice an earth connection for high frequency occurs due to the supply of the set from the power mains. Because of this, interference voltages may often occur between the receiving set and earth, which are due to sparking motors and similar apparatus connected with the same mains at some other point.

In *fig. 6* these interference voltages are indi-

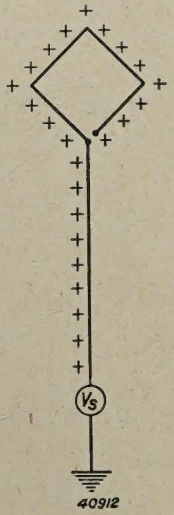


Fig. 6. A high-frequency interference voltage in the power mains can be represented in the case of loop receivers with mains connections as a source of voltage V_s in the earth connection of the loop. Such an interference voltage causes in the loop similar charge variations and consequently similar interference voltage to those caused by a vertical electric field.

cated by a source of voltage V_s. As may be seen, these interference voltages lead to an alternating charge on the loop, and this alternating charge will in turn result in an alternating voltage between the connections of the loop, which is proportional to the square of the frequency.

The relation discussed between aerial effect and sensitivity to interferences is confirmed experimentally. The less directional effect (the more aerial effect) a loop aerial exhibits, the more interference is experienced in reception, not only due to interfering electric fields acting on the aerial, but also due to interference voltages coming from the mains. Although these two interference phenomena are fundamentally of a slightly different nature, they thus usually have parallel results in practice.

Combatting the aerial effect

Different methods are used to combat the aerial effect, the three most important of which we shall discuss, namely :

1) Symmetrical construction.
2) Efficient shielding.
3) Diminishing the number of windings.

We shall confine ourselves to the case of a movable receiver which is connected with the mains, since in receivers with battery supply the aerial effect is not large enough to be disturbing.

1) *Symmetrical construction*

In the case of the symmetrical connections given in *fig. 7* the earth connection lies in the middle of the loop. The two halves have as nearly as possible the same surface area, the same self-induction and the same capacity with respect to earth and to their surroundings. The loading of the two halves is also made as equal as possible. In this way, for a vertically directed alternating electric field which thus lies in a plane of symmetry, the charging current flowing to the middle point of the loop is divided into two equal parts which flow in both directions, so that no voltage difference is generated between the ends of the loop. An alternating magnetic field, on the other hand, causes exactly the same alternating voltage as in the absence of the earth connection.

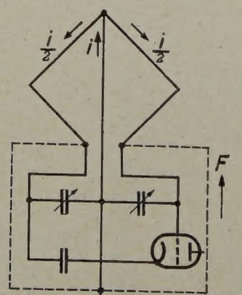


Fig. 7. Symmetrical connection of earth connection and input stage in a receiving set with loop aerial. An interference current *i* due to the electric field *F* causes no potential differences between the terminals of the loop, and consequently no variation of the control-grid voltage of the first amplifier valve.

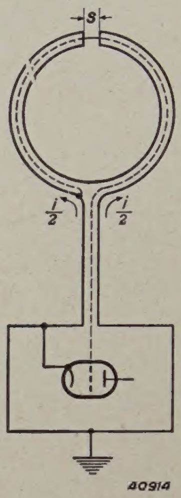


Fig. 8. Loop aerial (dotted line) surrounded by a shield. Thanks to this shield the loop winding is not exposed to electric fields. By means of the slit *s* circular currents are prevented in the shield. This is necessary, since otherwise the magnetic flux would also be shielded from the loop.

2) *Shielding*

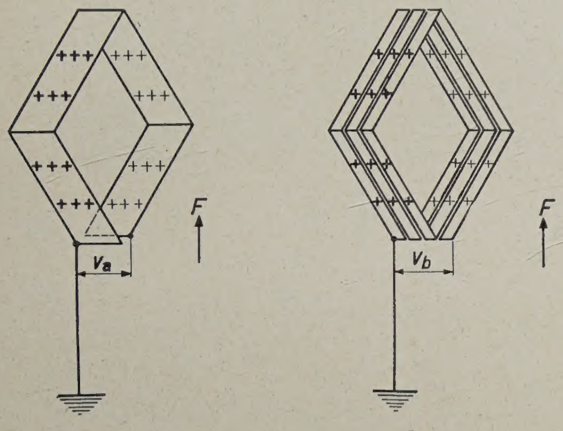
If a loop is surrounded by a shield which makes the entrance of electric fields impossible, the aerial effect is of course completely eliminated. In doing this care must naturally be taken that only electric fields and not magnetic fields are screened off. This can be done by introducing slits in the shield in such a way that the current cannot flow in closed loops which are magnetically coupled with the aerial.

In *fig. 8* an example is given of such a construction. The loop windings are housed in a tube which is interrupted by the slit *s*. The connection wires between aerial and receiver are shielded in the customary manner.

Upon the occurrence of an external alternating field or an AC voltage in the earth connection, charging currents will indeed flow in the shielding, but there will be no electric field inside. From this it may not, however, be concluded that no AC voltage occurs on the loop, since the charging currents also have a magnetic effect on the windings of the loop. If, however, as shown in the figure, the slit is made in the middle and the two arms of the shielding tube are made equal, then the magnetic effects of the charging currents in the left-hand and the right-hand tube compensate each other, so that no effect is exerted on the loop.

3) Limitation of the number of windings

With given dimensions of the loop aerial the voltage which is induced by an alternating magnetic field is proportional to the number of windings. The aerial effect, on the other hand, according to equation (2), is proportional to the self-induction, which increases with the square of the number of windings. From this it follows that the ratio between the aerial effect and the desired signal voltage becomes smaller as the number of windings is decreased.



a *b*

Fig. 9. Two externally identical loops which differ only in that *b*) is subdivided by a continuous slit in such a way that from a loop of originally one winding a loop of three windings is obtained. Its resistance and self-induction have thereby been increased by a factor 9.

In order to illustrate also this effect, let us consider *figs. 9a* and *b*, in which two loop aerials of equal dimensions are represented which are placed in a constant electric field F and earthed at one end. The only difference between the aerials consists in the fact that loop *b* has three windings while loop *a* consists of only one winding. With the same vertical field strength the charge on the two aerials will also be the same; if we then again pass over to an alternating field the same currents will flow in the earth connections. In loop *b*, however, this current must flow along a strip which is three times as long and 1/3 as wide as that of aerial *a*. From this it follows that the voltage drop along this path is 9 times as great. This holds for the ohmic as well as for the inductive component of the voltage drop.

Advantages and disadvantages of the different methods of combatting the aerial effect

In order to make a practical choice among the possibilities mentioned of combatting the aerial effect, we shall briefly discuss their advantages and disadvantages.

The *symmetrical construction* according to fig. 7 makes the input stage of the receiving set more complicated: it requires one more variable condenser, while the rest of the connections also become more complicated (floating cathode of the first valve or complete push-pull connections). The construction of the loop itself is also far from simple, considering the great precision required in the symmetry.

The *shielded loop* according to fig. 8 can be made much simpler and does not involve any complications for the input connections. The large capacity between the loop windings and the shielding in this case, however, forms a difficult problem. In order to decrease the effect of this zero capacity in the first tuning circuit, the self-induction of the loop can be chosen smaller than is desired for the first circuit and another coil can be connected in series with the loop. When this method is followed, however, the sensitivity and the ratio between signal energy and noise energy decrease.

If an attempt is made to decrease the capacity between loop and shielding directly by choosing constructions in which there is a large distance between the shielding and the windings, models are obtained which are unpleasant in appearance and which occupy relatively much space.

In the limitation of the number of windings the difficulty is encountered that the self-induction is decreased. For good matching of the tuning circuits it is desirable that the self-induction of the loop should be of the same magnitude as that of the other tuning circuits. This objection can, however, be met by connecting the loop not directly with the condenser but by means of a transformer (see *fig. 10*). If we assume that the transformer is ideal (no ohmic losses, no spreading, very large primary self-induction compared with the loop), the limitation of the number of windings results in no loss in sensitivity and no depreciation of the ratio of signal voltage to noise voltage, while a decrease of the aerial effect is obtained which is retained even after transformation. The last point is immedi-

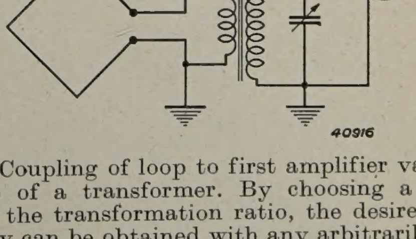


Fig. 10. Coupling of loop to first amplifier valve with the help of a transformer. By choosing a suitable value of the transformation ratio, the desired tuning frequency can be obtained with any arbitrarily chosen capacity of the rotating condenser and self-induction of the loop.

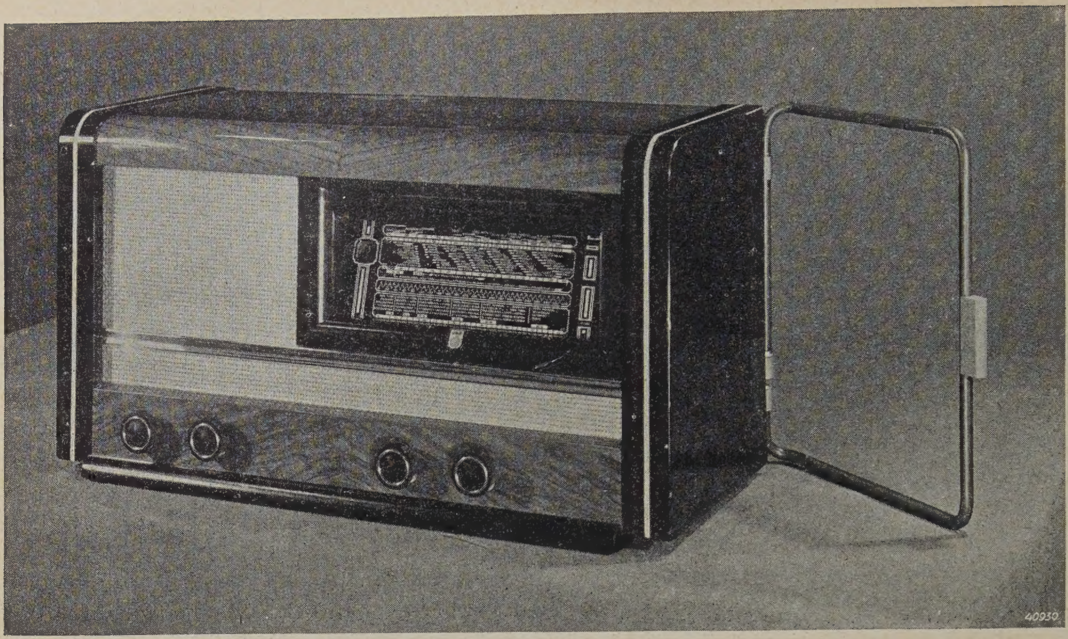


Fig. 11. The Philips receiving set 902 A with loop aerial.

ately clear, since the relation between the desired signal and the voltage which occurs due to the aerial effect is not altered by the transformation. Thus when a decrease in the aerial effect with respect to the desired signal occurs due to a decrease in the number of windings, this decrease is retained even after transformation.

The fact that the sensitivity and the noise actually do not change may be explained as follows. If L_1 is the self-induction of the loop and L_2 the desired self-induction the transformation ratio u is given by

$$L_2 = u^2 L_1.$$

On the other hand the self-induction could also be brought to the desired value by using no transformer, but by making the number of windings a factor n larger. The factor u is then determined by

$$L_2 = n^2 L_1,$$

so that $n = u$.

When the transformer is used the voltage is transformed upwards by a factor u, while upon increasing the number of windings the voltage which is induced by the magnetic field in the loop increases by a factor n. Since n and u are equal the voltage finally obtained is the same in both cases [5]).

It still remains to prove that an ideal transformer causes no change in the ratio between signal and noise.

If two connection terminals are introduced into any network consisting of resistances, capacities, self-inductions and mutual inductions, the mean square of the spontaneous fluctuation voltages between the terminals is proportional to the real part of the impedance measured between these terminals. If one now takes as connection terminals the secondary connections of the transformer, the relation between signal and noise is determined by an expression of the form V_2^2/R_2, where V_2 represents the open signal voltage between these terminals and R_2 the real component of the loop impedance as it is transformed in the secondary winding. Since

$$V_2 = u\ V_1 \text{ and}$$
$$R_2 = u^2 r_1$$

the expression V^2_2/R_2 is indeed independent of the transformation ratio.

Moreover, a change in the number of windings, with otherwise unaltered form of the loop, has no effect on V^2/R: the voltage V increases proportionally with n, while the resistance R increases with n^2, as mentioned in the discussion of fig. 9. V^2/R thus also remains constant.

In the practical application of the principle of limitation of the number of windings it is advisable to proceed so far that only one winding remains. The aerial can then be very simply constructed in the shape of a strong loop, which can easily be fastened to the set so that it can be turned. The directional effect can then be enjoyed without it being necessary to turn the set as well. From the aesthetic point of view also this is a satisfactory solution. It makes it possible to construct table sets with mains connection, which is not the case with symmetrical or shielded loop aerials, which for aesthetic reasons must be built into the set and can therefore only be considered for large cabinet models. The receiving set with loop aerial developed by Philips, type 902 A, is constructed on this principle [6]).

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[5]) For a voltage which occurs as a result of aerial effect this does not hold. Such a voltage is, as we have seen, proportional to the self-induction of the loop and thus to n^2. With a given form and size of the loop, therefore, the increase in the number of windings results in a greater increase in voltage than a corresponding transformation ($u = n$).

The Philips receiving set with loop of one winding

The receiving set 902 A (see *fig. 11*) is a table set for connection with the AC mains. It is a normal superheterodyne receiver with one stage of high-frequency amplification. The single loop is fastened to the right side so that it may be turned, and it has about the same dimensions as the side to which it is fastened. If the directional effect of the loop is not desired the loop can be turned around so that is it out of sight against the rear wall. Since appreciable attenuation of the strength of reception occurs only in a small angular region in the neighbourhood of the minimum, with this permanent orientation of the loop most stations can still be received satisfactorily.

The most important problem of construction in a set with a loop of one winding is formed by the transformer by which the loop is connected with the tuning condenser.

The transmission of the aerial voltage to the input circuit will always be accompanied by certain losses, since an ideal transformer does not exist. These losses have an unfavourable effect not only on the sensitivity but also on the relation between signal and noise. The problem is therefore to construct the transformer in such a way that these unfavourable influences are kept as small as possible.

Now the set has a large amplification reserve, so that a certain diminution of the sensitivity is permissible. Therefore in designing the transformer the chief aim was to obtain as large a value as possible of the ratio between signal and noise (this need not amount to the same thing as obtaining maximum sensitivity). In this way a construction is reached which differs quite considerably from the customary one; in particular the self-inductions of the transformer windings are unusually small.

After a suitable transformer had been successfully constructed, the loop aerial of one winding was found in every respect to be a suitable solution of the problem of a movable receiving set with low sensitivity to interferences and supplied from the power mains. It is suitable for all wavelengths of the broadcasting region; upon passing from one wave region to another it is only necessary to replace the transformer by one with a different number of secondary windings [7]). In the case of systems without a transformer the switching over is much more complicated: a different loop must usually be taken for each wave region, with the accompanying possible difficulties due to the requirement that the mutual coupling of the loops must be small in order to prevent the harmful influence of self-resonances of the loops intended for long waves.

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[6]) As may be seen from fig. 10, the loop is earthed at one end. The aerial effect is thus in principle still determined by the unfavourable arrangement of fig. 4, although the intensity of the unfavourable effect of the earth connection is considerably reduced by the decrease in the number of windings. If, however, it should be desirable to reduce the aerial effect still more, this can be achieved by earthing the primary winding of the transformer not at one end but in the middle. In practice this device has not been found necessary.

[7]) For the reception of short waves the transformer is omitted; then, compared with other aerial systems, the present system has no special advantages as far as the sensitivity to local interferences is concerned.

EXPERIMENTS ON THE PERMEATION OF GASES THROUGH METAL WALLS

by J. D. FAST.

620.193.29

The permeability of different kinds of metal for different gases is discussed on the basis of the theoretical conclusions stated in the previous volume of this periodical. It is found to be possible to point out one or more examples of each of the theoretically distinguishable cases. These examples are discussed and a description is given of the apparatus used by the author in the necessary experiments. The great influence is also shown of the nature of the surface in many cases on the permeability of the walls. Further conclusions are drawn about the avoidance of the difficulties to which the permeability of walls may lead in high-vacuum technique. In conclusion quantitative data are given on the way in which the permeability depends upon the temperature, while it is pointed out that the selective permeability of walls may be used for the purification and analysis of gases.

Introduction

In the previous volume of this periodical¹) the phenomenon of the penetration of gases through metal walls was discussed. Briefly that discussion may be summarized as follows. In the most interesting cases the penetration does not occur as a result of the presence of "leaks" in the ordinary sense of the word, but as a direct result of the atomic structure of matter. Atoms (or ions) of gaseous elements are found in certain cases at not too low temperatures to be able to move between the atoms of the metal wall. Since these interstices are normally filled with electron "gas", this is true only of atoms which possess one or more unpaired electrons in the uncharged state²). The possibility of dissolving and diffusing therefore exists only for those gases whose molecules for the same reason consist of pairs of atoms outside the metal. As examples of gases whose atoms possess one, two or three unpaired electrons we may mention hydrogen, oxygen and nitrogen respectively.

As a result of their consisting of two atoms in the gas phase, the permeation of gases through metal walls requires at least five successive processes.

Aa): Splitting of the molecules into atoms (or ions) on the entrance surface.

Ab): Penetration of the atoms (ions) formed into the metal.

B): Diffusion in the metal.

Ca): Transition from the dissolved state into the adsorbed state on the exit surface, *i.e.* the opposite of Ab).

Cb): Recombination of the adsorbed atoms (ions) to molecules, *i.e.* the opposite of Aa).

The velocity of the total process of permeation will be mainly determined by the velocity of the slowest of these five processes. Five different cases can thus be considered in each of which a different process determines the velocity, and we shall show in this article that all five of these cases can actually be realized. Examples are :

Aa: Hydrogen through an iron wall.

Ab: Hydrogen through an iron wall with a very rough entrance surface.

B: Hydrogen through a copper wall.

Ca: Oxygen through a zirconium wall.

Cb: Hydrogen through a palladium wall and oxygen through a copper or a nickel wall.

Aa) Permeation of hydrogen through an iron wall

One will in the first instance be inclined to hunt for the cases in which the reaction on the entrance surface determines the velocity of the permeation among those systems of gas and metal in which the energy level of the gas in the metal is higher than outside the metal. In *fig. 1* it is shown how the solubility of hydrogen at a pressure of 1 atmosphere in several metals depends upon the temperature³). It may be seen that there are metals whose solvent capacity for hydrogen increases with the temperature, and others of which the reverse is true. In the first group the heat of solution is negative, and one of these systems, namely the system iron-hydrogen, is indeed an example of a case in which the reaction at the entrance surface determines the velocity of permeation. Upon closer consideration it is found that the entrance surface may still exist in two states whereby in one case the splitting of hydrogen molecules into atoms and in the other the transition of

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¹) Philips Techn. Rev. **6**, 365, 1941.

²) Two electrons are termed "paired" when they differ only in the spin quantum number. It is the electrons with non-compensated spins which are in the first instance responsible for the cohesion of atoms to larger aggregates in the form of the molecules of chemical compounds, or for instance of the abovementioned solid solutions.

³) The figure is analogous to a figure in an article by G. Borelius, Ann. Physik **83**, 121, 1927, but elaborated according to the latest experimental data, which, like the older data, are mainly due to A. Sieverts and his co-workers.

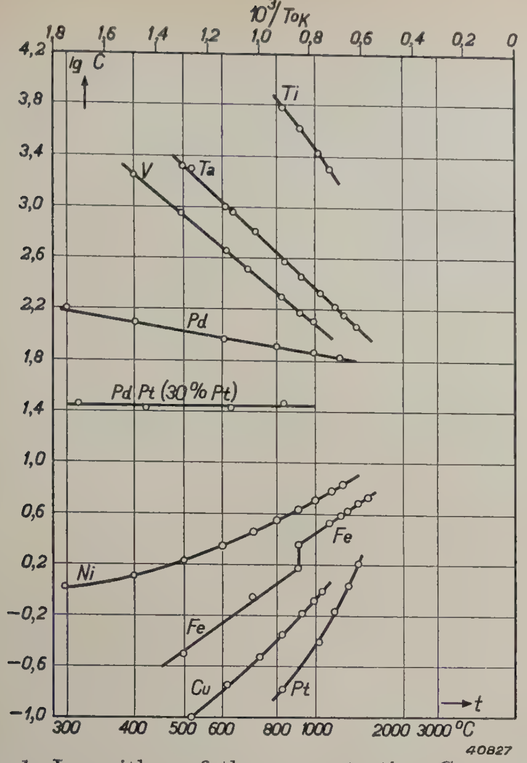

Fig. 1. Logarithm of the concentration C, expressed in atoms of hydrogen per 10^4 atoms of different metals at a pressure of 1 atmosphere, as a function of the reciprocal of the absolute temperature. For titanium, tantalum, vanadium and palladium this solubility decreases with increasing temperature, while for nickel, iron, copper and platinum it increases with the temperature. For an alloy of 70% palladium and 30% platinum the solubility of hydrogen is practically independent of the temperature.

the adsorbed atoms to the interior of the metal determines the velocity of permeation. In the case of walls which are not expressly made very rough we are concerned with the first case. We shall begin by discussing it in some detail.

It is found that iron walls only begin to transmit appreciable quantities of hydrogen above 200 to 300°C, when one side of them is brought into contact with molecular hydrogen. If on the other hand the gas, by the action of an acid or electrolytic development, is supplied to the entrance surface in atomic form, rapid permeation already occurs at room temperature. Since the conditions here are very complex, several experiments were carried out in this laboratory with gaseous atomic hydrogen [4]). One side of an iron wall was in connection with an evacuated space (H in *fig. 2*), the other with a space B in which hydrogen atoms were formed by thermal dissociation of hydrogen molecules on a glowing tungsten spiral. The dissociation took place under such circumstances that the formation of ions was out of the question.

Fig. 2 is a sketch of the apparatus used. The iron wall is situated at A and consists of a circular plate about 50 microns thick which divides a glass vessel into two parts (H and B). In B the tungsten spiral

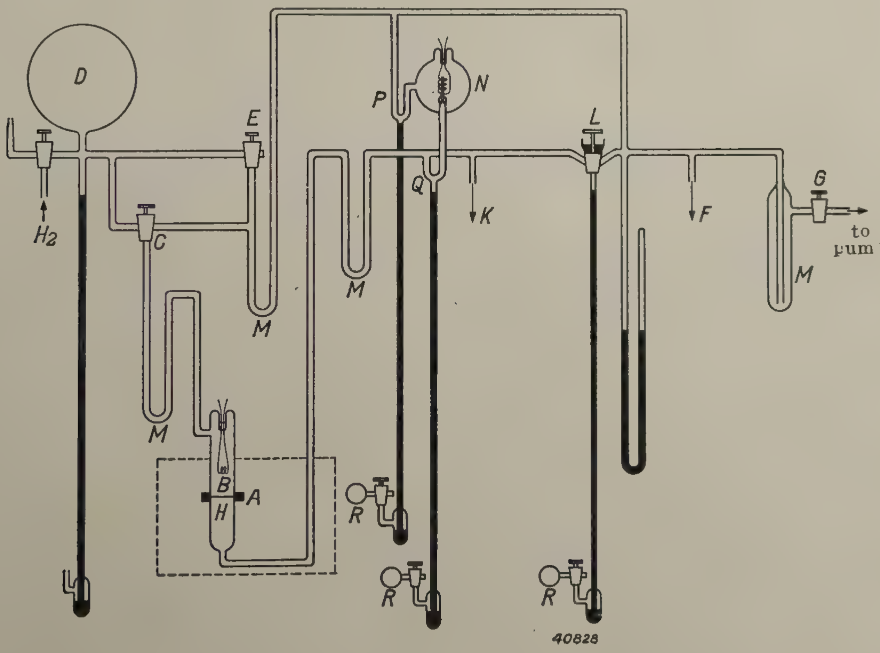

Fig. 2. Sketch of the apparatus for measuring the permeability of metal walls for hydrogen. A is an iron wall which separates the measuring vessel into two parts B and H; in B is a tungsten heating spiral. The part of the apparatus surrounded by a dotted line is placed in a thermostat. C and E stopcocks, D hydrogen reservoir. At F and K Mac Leod manometers are connected. L mercury seal and G stopcock leading to the high-vacuum pumps. M coolers for freezing out water vapour and stopcock grease. N bulb with a palladium tube with which the gas in H can be tested to ascertain whether it is really hydrogen and with which at the same time the gas can be purified. P and Q mercury seals operated with the rubber bulbs R.

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[4]) J. H. de Boer and J. D. Fast, Rec. trav. chim. Pays Bas **58**, 984, 1939.

is situated 4 to 5 cm away from the iron wall. The part of the apparatus between the dotted lines was placed in a water thermostat at 25° C during the experiments. *Via* stopcock C the space B could be connected with the hydrogen reservoir D in which the pressure of the carefully purified gas (the purification apparatus is not shown) could be varied as desired between 0 and 1 atmosphere. *Via* the stopcocks C and E, however, the space B could also be connected with a MacLeod manometer F and at the same time *via* stopcock G with the high-vacuum pumps. The space H on the other side of the iron wall was connected with a MacLeod manometer K and, *via* the mercury seal L and the stopcock G, could also be connected with the high-vacuum pumps.

Before an experiment was performed the iron membrane A was always tested to see whether it was tight for molecular hydrogen. For this purpose the space B was filled with hydrogen at 1 atmosphere and the space H was evacuated carefully for a long time. The requirement was then made that after this, with stopcock L closed, the pressure in H should remain too small to be measured for 24 hours ($< 10^{-6}$ mm). After this had been ascertained, the experiment proper could be begun.

In the experiment proper the hydrogen pressure in B was first brought to the desired value and the tungsten spiral was then heated to 2000° C. If the hydrogen pressure was greater than 1 mm of mercury, the pressure in H did not increase, apparently due to the fact that all the hydrogen atoms formed on the glowing surface recombine before they reach the iron wall. If on the other hand the pressure was of the order of 0.1 mm or less, the heating of the tungsten spiral resulted in a rapid increase of the pressure in H. *Fig. 3* gives as an example the pressure in H as a function of the time in an experiment in which the hydrogen pressure in B was kept practically constant (about 0.1 mm). If the heating of the tungsten spiral is only continued long enough the space B and that connected with it is completely evacuated due to the fact that all the hydrogen is finally transported through the iron wall to H. The permeation thus also takes place against an excess pressure because of the fact that the molecular hydrogen which accumulates at the exit side cannot penetrate into the iron and diffuse back at 25° C.

If hydrogen atoms are formed in hydrogen at a low pressure, they are also adsorbed on the glass walls. Several series of experiments were so performed that in addition to the increase in pressure in H the decrease in B and, moreover, the amount adsorbed could be measured. In one of these experiments a known amount of pure hydrogen was used, which upon opening the stopcock L was allowed to spread throughout the spaces $HKLFCB$. The tungsten spiral was then heated to 2000° C, while the spaces B and H were still connected with each other. Curve *1* in *fig. 4* shows the decrease in pressure as a result of the adsorption on the glass walls. After 3 hours L was closed, whereupon the pressure in H immediately began to rise with great velocity (curve *3*) and that in B to fall (curve *2*). As may be seen, the experiment was continued until space B was practically evacuated. *Fig. 5* gives the same curves as fig. 4, but recalculated by means of the known volumes on the basis of amounts of hydrogen at 0° C and 1 atmosphere. Curves *2* and *3*, as could be expected, are now exact mirror images of each other.

From the experiments it is found that already

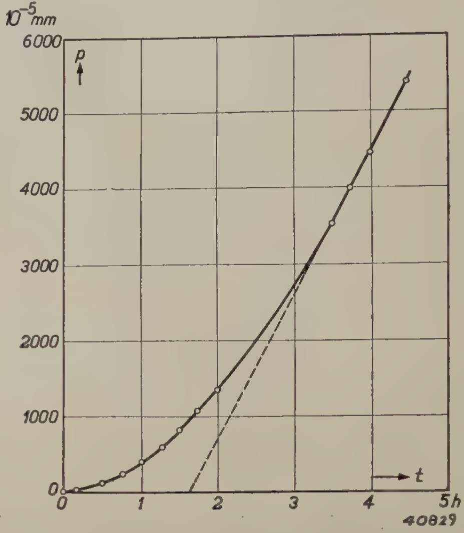

Fig. 3. The variation of the pressure p in space H of fig. 2 as a function of the time t at an approximately constant hydrogen pressure of 0.1 mm in B and a temperature of 2000° C of the tungsten spiral.

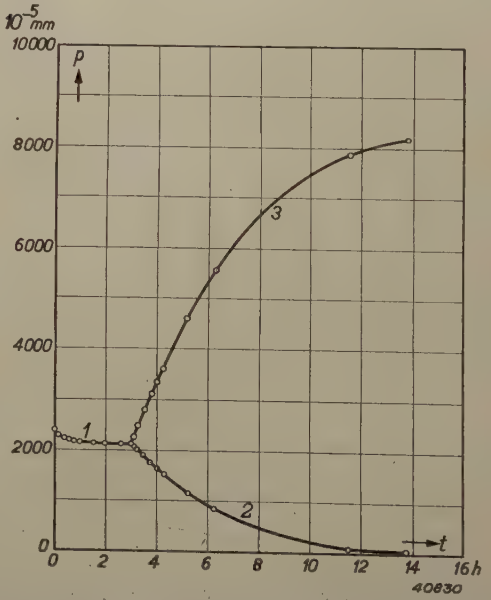

Fig. 4. The pressure p in the whole apparatus decreases slightly when the tungsten spiral is heated, as long as L in fig. 2 remains open, due to the adsorption on the walls (*1*). After 3 hours the mercury seal L is closed and the pressure in H begins to rise rapidly (*3*), while that in B falls nearly to zero (*2*).

at room temperature hydrogen atoms can penetrate into an iron wall, they possess great mobility in the metal and can easily leave the exit surface after recombination. The presence of an excess pressure of molecular hydrogen at the exit side constitutes no hindrance to this process. The process which determines the velocity upon supply of molecular hydrogen is thus the splitting of molecules into atoms on the entrance surface.

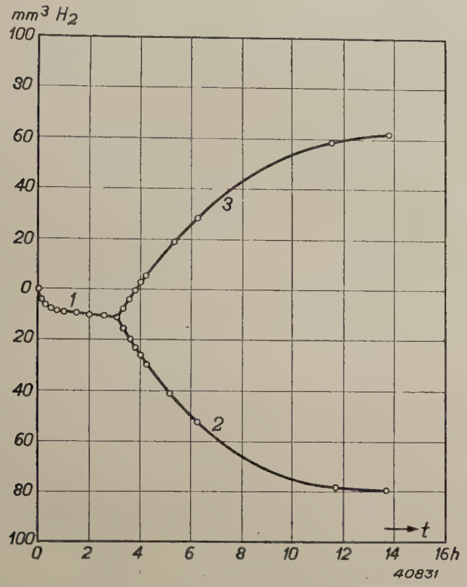

Fig. 5. The same phenomenon is shown as in fig. 4. The pressure in mm of mercury is here, however, recalculated into mm³ of hydrogen at 0°C and 1 atmosphere, whereupon curves *2* and *3* become mirror images of each other.

Ab) Permeation of hydrogen through an iron wall with a very rough surface

Remarkably enough, from measurements of the adsorption of hydrogen on specimens of iron in the powder state [5]) it is found that activated adsorption, *i.e.* splitting of molecules into atoms, already occurs at room temperature. On the rough irregularly shaped surfaces of the grains of which such powders consist the splitting thus already occurs at an appreciably lower temperature than is the case on the relatively smooth surfaces of iron walls. The phenomena are thus very closely connected with the nature of the surface, and in connection with this it is obvious that the entire surface of the iron powders cannot be assigned the same activity. It must rather be assumed that at certain "active spots" the energy of activation of the atomic adsorption is very small and that all possible conditions between slightly and very active spots exist [6]).

It may now be asked what will happen when by mechanical or chemical means one side of an iron wall is made very rough and molecular hydrogen is supplied to this side. Apparently even at room temperature activated adsorption will occur, and in connection with the foregoing one would perhaps be inclined to expect that the wall will now also already allow the passage of hydrogen. It is, however, more probable to expect that the hydrogen atoms (ions) formed on the surface are bound to sharp points and edges, and, from the point of view of energy, they are there so much more favourably placed than in the interior of the metal that the energy difference between these two conditions at room temperature cannot yet be overcome by an appreciable fraction of the atoms. If this is correct, the permeability of an iron wall upon being supplied with atomic hydrogen should become smaller upon making the entrance surface rough. On the other hand it may be expected that the permeability will become greater if the hydrogen is supplied in the molecular form. The activation energy which is necessary for the splitting of molecules into atoms has become much smaller due to the roughening of the surface. At higher temperatures the hydrogen atoms will be able to migrate over the surface to spots where they can more easily penetrate into the metal. This is in many cases, as represented diagrammatically in *fig. 6*, already equivalent to a partial penetration into the metal.

The facts observed are found to agree entirely with the expectations just mentioned. If an iron wall is made in the form of the cathode of a glow discharge in hydrogen [7]) the gas is supplied to the entrance surface in the form of ions. In ordinary cases part of the ions are to leave the metal on the other side. When however, regular scratches were made on the entrance side the permeability decreased, and with steadily decreasing distance between the scratches it finally fell to practically zero (at room temperature).

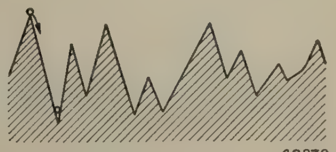

Fig. 6. Diagrammatic representation of a surface along which diffusion takes place. It is clear that this may be equivalent to a partial penetration into the metal.

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[5]) For references to the literature, which are not given fully in this article, the reader is referred to: Chem. Wbl. **38**, 2 and 19, 1941.

[6]) This conception corresponds completely with experience gained in the field of heterogeneous catalysis, where often only a fraction of the total surface of the catalyst exhibits catalytic activity.

[7]) H. Betz, Z. Phys. **117**, 100, 1940.

On the other hand it has been observed [8]) that the permeability of iron and nickel when molecular hydrogen is supplied can be appreciably increased by making the surface rough (by chemical methods). A permeability already observable at room temperature cannot, however, be obtained under these conditions by making the surface rough.

In the example given it must further be expected that certain catalyst poisons will exhibit an effect which is the opposite of that of making the surface rough. Macroscopically smooth surfaces probably also still possess somewhat active spots which can be rendered inactive by such poisons. In complete agreement with this expectation it is found for instance that certain arsenic and mercury compounds in electrolytic experiments, and sulphur compounds in etching experiments cause the amount of hydrogen transmitted to increase considerably. Conversely, with the application of hydrogen in the molecular form a poisoning of the surface (in this case by a chemisorbed layer of oxygen) is found to cause a decrease of the permeability.

It must therefore be assumed that the surfaces will in general not be uniform. The activation energies of adsorption and desorption and the heat of adsorption will vary in many cases from point to point. The character of a rough surface will, however, be determined mainly by the most active spots. Upon application of molecular hydrogen the splitting into atoms takes place chiefly on these spots. Upon the application of atomic hydrogen also these spots play an essential part, as will appear from the following. The activation energy of the surface diffusion will be relatively small on the smooth parts of the surface, smaller than the energy necessary for the penetration into the metal and that necessary for recombination. A large number of the atoms which alight on these smooth parts therefore already move over the surface at room temperature. When two atoms meet, recombination takes place if they have sufficient energy to make up the required activation energy. Part of the atoms moving over the surface, however, disappear into the interior of the metal before they have the opportunity of recombining. If the smooth parts are small, most of the atoms reach the active spots and are fixed there at room temperature, due to the fact that the binding forces are much stronger there. Upon a continued application of atomic hydrogen these active spots will act as recombination centres. There is reason to assume that they lower not only the activation energy of dissociation, but also that of recombination. The fact that recombination always takes place more rapidly on rough surfaces than on smooth ones supports this assumption.

If this is correct, then upon the application of atomic hydrogen a change in the nature of the exit surface should have an effect on the permeability opposite to that of the same change in the nature of the entrance surface. The influence must, however, be much smaller, since it is clear from the foregoing that the permeability of an iron wall for hydrogen is mainly determined by the entrance surface. It is indeed found that the permeability can be increased by making the exit surface rough, but only by a factor 2. Upon the application of molecular hydrogen such parallel changes in the nature of entrance and exit surfaces will on the other hand change the permeability in the same direction.

The table gives a survey of the influence of different factors.

Permeability	by roughening	by smoothing (poisoning)	by roughening	by smoothing (poisoning)
	of the entrance surface		of the exit surface	
for atomic hydrogen	decreased	increased	increased	decreased
for molecular hydrogen	increased	decreased	increased	decreased

B) Passage of hydrogen through a copper wall

The case in which the velocity of diffusion in the metal determines the permeability also appears to exist. This can be deduced with fairly great probability from measurements of the permeability of complex membranes Cu-Pd-Cu and Pd-Cu-Pd for hydrogen [9]). At 400° C the permeability of palladium for hydrogen is 10^5 tot 10^6 times as great as that of copper. If the total thickness of the copper in both complex membranes is the same, the same permeability will be expected for both if the transmission of the copper is not determined by a process on one of the boundaries between gas and metal. If, however, the latter is true, very divergent permeabilities must be expected. The permeabilities were found to be the same.

Ca) Passage of oxygen through a zirconium wall

An example of a case in which the reaction at the exit surface determines the permeabiilty is the passage of oxygen through a zirconium wall. The heat of solution is strongly positive and the energy level of the oxygen in the metal is thus very low. For the chemisorption on the surface very little or no activation energy is needed. At room temperature and lower temperatures zirconium is already covered with a film of oxide upon exposure to gaseous oxygen. The penetration of the oxygen requires a much larger energy and only takes place with appreciable velocity above 600° C. At temperatures above 1000° C, for instance, the velocity of diffusion of the oxygen in the metal is fairly high. In spite of this it is impossible to drive the oxygen dissolved in zirconium out again by heating to a very high temperature in a high vacuum. At the exit surface therefore an insurmountably large energy difference must be overcome. There are indications that this large activation energy is required for the transition of the atoms (ions) from the dissolved to the adsorbed state.

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[8]) C. J. Smithells and C. E. Ransley, Proc. Roy. Soc. A, **150**, 172, 1935.

[9]) H. W. Melville and E. K. Rideal, Proc. Roy. Soc. A, **153**, 89, 1935.

The case discussed clearly demonstrates how necessary it is to make a sharp distinction between permeability and velocity of diffusion: the permeability of a zirconium wall for oxygen is zero notwithstanding the high velocity of diffusion in the metal.

Cb) Passage of hydrogen through a palladium wall and of oxygen through copper walls

For the passage of hydrogen through walls of metals such as palladium, zirconium, tantalum, etc. the rate-determining process must be sought at the exit surface. In this case the energy level in the metal is lower than outside (see fig. 1). In contrast to the passage of oxygen through zirconium walls, however, the permeability at high temperatures is greater than zero. We shall consider the system palladium-hydrogen as an example.

From many experiments it is known that palladium in contact with molecular hydrogen can take up large quantities of this gas at room temperature or slightly higher temperatures, if the surface is in a favourable condition. Moreover, the velocity of diffusion in the metal under the same conditions is already quite high. Below 100° C, however, the gas is unable to leave the metal. In order for the hydrogen to leave the metal, therefore, a much larger activation energy is required than for entering it or for diffusion in the metal. This larger activation energy is apparently not required for the transition of the hydrogen atoms from the dissolved state into the adsorbed state, but for the recombination of the adsorbed atoms (ions) on the surface. At room temperature palladium does indeed lose hydrogen when it is situated in an atmosphere containing oxygen, apparently due to the fact that the hydrogen atoms on the surface react with the oxygen.

A second example in which the recombination on the exit surface determines the velocity of permeation is the passage of oxygen through copper walls. Upon heating copper which contains oxide to a high temperature, the larger oxide particles in the metal rapidly increase in size at the expense of the smaller ones, from which it is clear that the oxygen is able to diffuse in the copper. Upon heating copper containing oxygen in a high vacuum, however, it is impossible to drive the oxygen out at temperatures at which the copper itself does not evaporate appreciably. If on the other hand the heating is done in an atmosphere of carbon monoxide, which is insoluble in copper and which cannot therefore penetrate into it, the copper loses its oxygen fairly rapidly with the formation of carbon dioxide. If carbon monoxide is present then the recombination of the oxygen atoms is superfluous, since a CO molecule can react directly with an adsorbed O atom and form CO_2.

Several technical questions and quantitative data

Hydrogen-iron

The high velocity of diffusion which hydrogen exhibits at room temperature in several metals, especially iron, has led to various types of difficulties in technology. If the gas is developed on the surface of the iron in atomic form, for instance in etching or electrolytic development, it may, as discussed in the foregoing, penetrate into the metal and cause serious damage when small cavities or non-metallic occlusions are present in the metal. At those points the gas passes over into the molecular form (*i.e.* into a form in which it can no longer diffuse), and may cause enormous internal pressures. Because of this, intercrystalline cracks and bubbles filled with hydrogen (blisters) may appear on the surface. If for example electrolytic hydrogen[10]) is developed on the outside of a hollow iron cylinder, the pressure in the cylinder can be raised to 500 atmospheres. The high internal pressure does not have the least retarding effect on the speed at which the pressure increases, and it is, for reasons of safety only, advisable to interrupt the experiment at 500 atmospheres.

Even when there are no discernable cavities in the metal the hydrogen taken up is detrimental, because it causes a large depreciation in the ductility. This is only of a temporary nature, since the gas is able to leave the metal at room temperature. The original condition however, is, never entirely regained, probably because the metal actually always contains submicroscopic cavities, perhaps in the form of points where only a few iron atoms are missing. Of this type of "holes" the largest can probably be expected at the grain and mosaic boundaries and in cold-worked metal at the slip planes (the specific weight of cold-worked metal is smaller than that of stress-free metal).

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[10]) C. A. Zapffe and C. E. Sims, Metals and Alloys, **11**, 177, 1940.

High-vacuum technique

In connection with the foregoing it will be clear that in the case of high-vacuum tubes whose walls are made partly or entirely of metal one must always be on one's guard against hydrogen, especially when this gas is present in the form of atoms or (non-hydrated) ions. The most striking phenomena again occur in the case of iron walls. Merely cooling the outside with water spoils the vacuum on the inside. Atomic hydrogen is formed on the outside surface by corrosion, and part of this, after diffusion, recombines on the inside surface to hydrogen molecules. In this laboratory the relation between permeation and corrosion was investigated by making use of solutions of different degrees of acidity. The apparatus was about the same as in fig .2 with the difference that it was now in addition possible to admit different solutions to B. Corrosion with the formation of atomic hydrogen was found to be the necessary condition for the occurrence of permeation. Neutral reacting and weakly basic liquids caused no corrosion and likewise no permeation; acid liquids had a corroding action already with a hydrogen-ion concentration of 10^{-6} ($p_H = 6$), which often occurs in water from the mains. With increasing degree of acidity the corrosion and the permeation increased. *Fig. 7* shows the increase of the pressure in the measuring space (H) as a function of the time for a solution with a hydrogen ion concentration of 10^{-6} (area of surface of iron 0.8 cm^2, thickness of wall about 50 μ, volume of measuring space about 1 liter). The amount passed through was of the same order of magnitude as the total amount developed. From the experiments it is evident that the hydrogen ions which are formed in the chemical reaction can penetrate into the iron, but that the presence of (hydrated) hydrogen ions in the liquid does not cause any taking up of hydrogen.

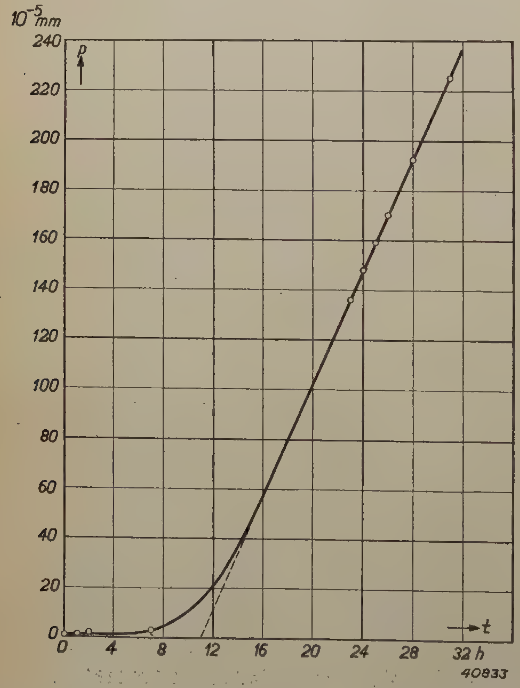

Fig. 7. Increase in the pressure in space H of fig. 2 with the time t when the wall A is in contact with a solution having a hydrogen-ion concentration of 10^{-6} g per litre which fills space B.

Not only by replacing the iron by another metal but also by the application of a different method of cooling, the difficulties described can be overcome. In the first case use is usually made of an alloy of iron with chromium or of pure copper. These metals are not only much more resistant to corrosion, but even when atomic hydrogen is expressly developed on the entrance surface a much smaller fraction of it permeates through the wall at room temperature than in the case of iron. Moreover, it will be shown (fig. 8) that upon exposure to molecular hydrogen the permeation only begins to become appreciable at much higher temperatures than with iron. In the second case use is made of cooling with non-corroding liquids or air-cooling. It is also possible to continue to use the combination of iron and water, but to cover the outside of the iron with a protecting metallic or non-metallic layer. This safety device is also necessary when the iron walls are not cooled, since an unprotected surface of iron is subject to corrosion in air.

Several quantitative data

The way in which the permeability m depends upon the absolute temperature T is found in all cases investigated to be satisfactorily represented by the formula

$$m = A\, e^{-Q/RT}, \qquad (1)$$

where A and Q are constants and R the gas constant.

The diffusion constant D, which indicates the velocity of transport of matter in a homogeneous medium, depends on the temperature in an analogous manner ¹)

$$D = A' e^{-Q'/RT}, \ldots\ldots\ldots \quad (2)$$

where Q' represents the heat of diffusion, *i.e.* the activation energy in diffusion.

Even in the case where in the permeation of a wall the diffusion in the metal determines the velocity (copper-oxygen) the significance of Q in formula (1) is not the same as that of Q' in formula (2), but may be described in the following way. The diffusion in the metal is in this case slow compared with the reactions on the boundary surfaces, so that it may be assumed that the equilibrium concentrations c_1 and c_2 are established in the metal immediately below entrance and exit surfaces. For a wall of unit thickness $c_1—c_2$ indicates the concentration gradient in the wall, and the amount which diffuses per cm² and per sec through the metal wall is then given by

$$m = D(c_1 - c_2) \ldots\ldots\ldots \quad (3)$$

If a vacuum is maintained at the exit side, c_2 becomes equal to zero and equation (3) becomes

$$m = Dc \ldots\ldots\ldots\ldots \quad (4)$$

In a first approximation c varies according to $e^{-Q''/RT}$ with the temperature, where Q'' represents the heat of solution. The dependence of m on the temperature is thus given by a formula of the form

$$m = Ae^{-Q'/RT} \cdot e^{-Q''/RT} = Ae^{-(Q'+Q'')/RT} \;.\;. \quad (5)$$

Thus Q in formula (1) in this case is $Q' + Q''$, the sum of the heat of diffusion and the heat of solution. This sum is less than the heat of diffusion when the solution is an exothermic process and greater when it is an endothermic process.

If the boundary surfaces play an important part Q takes on quite a different significance. In the passage of hydrogen through an iron wall with smooth surfaces Q will be mainly determined by the activation energy required for the dissociation of a gram molecule of hydrogen into atoms (on the surface). In the passage of oxygen through copper and of hydrogen through palladium the activation energy of desorption plays this part.

In the table below the values of A and Q of formula (1) will be found for several combinations of metal and gas, as well as the values of m for 400, 500, 500, 700 and 800 °C. In order to obtain practical values m and A are not expressed in c.g.s. units but in cm³ per dm² per hour with a thickness of wall of 1 mm and at a gas pressure of 1 atmosphere at the entrance side and 0 atmospheres at the exit side. *Fig. 8* gives log m as a function of $1/T$ for these combinations of gas and metal.

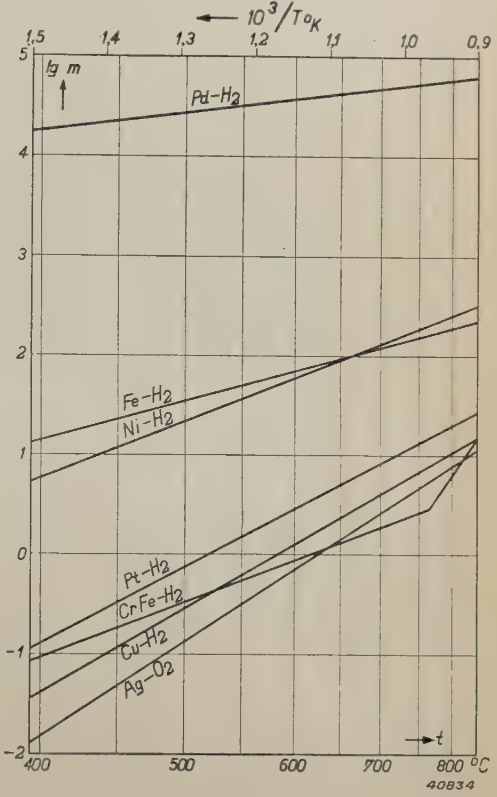

Fig. 8. Logarithm of the permeability m for different combinations of metal and gas, expressed in cm³ per dm² per hour with a wall thickness of 1 mm and gas pressures of 0 and 1 atmosphere, respectively, on the two sides of the wall, as a function of the temperature t. The reciprocal of the absolute temperature T (upper scale) is used as abscissa.

Purification and analysis of gases

Use is often made of the very high permeability of palladium for hydrogen in order to obtain the gas in a very pure state. If the palladium is heated to not too high a temperature (400 to 500° C for instance) only hydrogen and no other gas passes through it. The partial hydrogen pressure must, however, be kept low (not more than several cm mercury pressure), since otherwise the palladium very soon begins to exhibit macroscopic leaks. Use is also made of the selective permeability of hydrogen to determine the amount of hydrogen in a mixture of gases. Both possibilities were used with the apparatus of fig. 2.

In an analogous way silver can be used to obtain pure oxygen out of the air or from another gas mixture.

TABLE

Permeability $m = Ae^{-Q/RT}$ of different walls for different gases

			m_t (t in °C) in cm³ per dm² per hr				
System	A (cm³/dm² hr)	Q (kcal/mole)	400°C	500°C	600°C	700°C	800°C
Pd - H_2	4.1×10^5	4.2	18000	27000	37000	47000	58000
Fe - H_2	1.6×10^4	9.5	14	35	70	121	192
Ni - H_2	1.4×10^5	13.5	6	22	61	137	261
Pt - H_2	1.1×10^5	18.4	0.13	0.74	2.9	8.5	20
Cu - H_2	1.2×10^5	20.0	0.041	0.29	1.3	4.1	10.5
CrFe - H_2	1.8×10^3	13.3	0.09	0.33	0.88	1.9	—
Ag - O_2	3.0×10^5	22.6	0.015	0.13	0.72	2.7	8.1

MODULATORS FOR CARRIER-TELEPHONY

by F. A. DE GROOT and P. J. DEN HAAN.

621.396.619:621.395.44

The modulator of a carrier-telephone channel has as its function the modulation of the low-frequency speech vibrations on a carrier wave, while in most cases the carrier itself must be suppressed. In this article it is explained how this can be realized with a simple push-pull connection of two valves. By doubling the push-pull circuit (for instance in the form of a ring modulator) the efficiency of the modulator is improved. In addition to the desired side bands many undesired components also occur at the output of the modulator, and this is investigated here in different steps. The input signal is first assumed to be very small and a certain simple characteristic is assumed for the valves. The influence of stronger input signals is then investigated and also that of any given valve characteristic. Upon application of the double push-pull connections the last-mentioned generalization is found to have no effect. In conclusion the practical construction of the modulators is discussed with special emphasis on the effect of slight dissymmetries and the means of suppressing the carrier-wave leak caused thereby.

The fundamental features of carrier-telephony and the general construction of a carrier-telephone installation were recently dealt with at length in this periodical [1]). The principle may be summarized as follows. The speech currents which arrive in station A from the microphone of a subscriber (see *fig. 1*) are fed to a modulator over a fork connection and a low-pass filter. This modulator modulates the low-frequency speech vibrations on a carrier of higher frequency f, *i.e.* it causes the formation of two side bands of the carrier wave, one of which corresponds to a displacement of the frequency spectrum of the speech by an amount f, while the other is the mirror image of the first with reference to the carrier-frequency. The A.C. voltages thus obtained are fed to a band filter which suppresses one of the side bands. The side band passed is transmitted to station B *via* a telephone line with repeaters, where with the help of a demodulator it is brought back to the original low-frequency vibrations and supplied to the desired subscriber. By applying this process to the speech vibrations, using a different carrier-frequency each time, several conversations can be transmitted simultaneously over one pair of conductors.

In this article we shall discuss one of the most important components of such a system, the modulator. In order to make its action clear we shall first consider an apparatus which is used for other purposes in telephony and telegraphy, and which may be termed the blocking element.

The blocking element

The blocking element consists of connections according to the principle represented in *fig. 2*. Two rectifier valves a and b are connected between two transformers T_1 and T_2, and it is assumed that with a voltage in one direction (blocking direction) they have an infinitely large resistance and with a voltage in the opposite direction (transmitting direction) they have no resistance or at least a resistance of a small constant value. The behaviour of such a valve

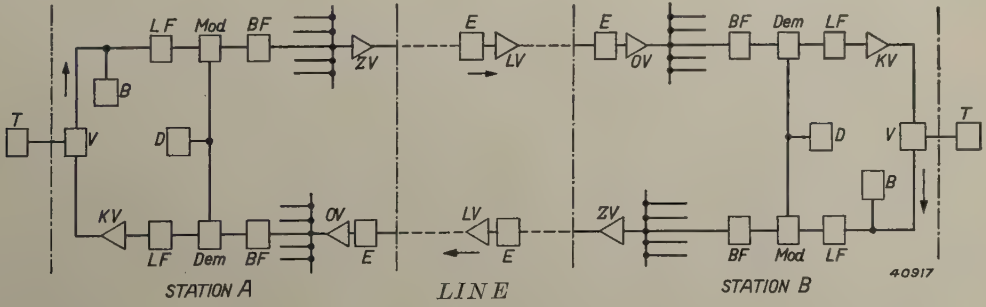

Fig. 1. Simplified diagram of a carrier-wave telephone channel. T subscriber's apparatus, V fork connection, B voltage limiter (for the avoidance of overloading of the repeaters), LF low-pass filter, *Mod* Modulator, BF bandfilter, ZV transmitting repeater, E equalization network, LV line repeater, OV reception repeater, *Dem* demodulator, KV channel repeater, D carrier-wave generator.

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[1]) D. Goedhart and J. de Jong, Carrier-telephony, Philips Techn. Rev. **6**, 325, 1941.

is thus described by a characteristic of the form sketched in *fig. 3.* If an A.C. voltage now acts on the input terminals *1—2* and a D.C. voltage greater than the amplitude of the transformed A.C. voltage on the terminals *5—6* (centre taps of the transformers), with the polarity of the D.C. voltage indicated a voltage in the blocking direction continually acts on each valve. Due to the blocking action of the valves, no current can flow, *i.e.* at the output terminals *3-4* of the blocking element none of the input voltage appears. If, however, we reverse the polarity of the D.C. voltage, a voltage in the transmitting direction always acts on the valves; the secondary voltage of T_1 now causes a current which in turn causes an A.C. voltage at the output. Depending on the polarity of the D.C. voltage on *5-6*, therefore, the connections will block or transmit an A.C. voltage acting on *1-2*.

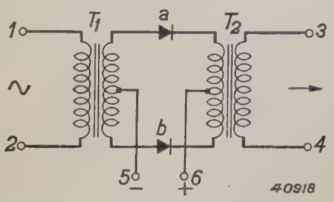

Fig. 2. Blocking connections. *1-2* input terminals, *3-4* output terminals; T_1, T_2 transformers; *a b* rectifier valves. The arrowhead of the symbol for the valves indicates the transmitting direction.

It is clear that the blocking element acts as a switch, which is operated by reversing the polarity of a D.C. voltage. The same function could, for instance, also be entrusted to an electromagnetic relay. Compared with such a relay, however, the blocking element has not only the advantage that it requires practically no maintenance, — especially upon the use of blocking-layer rectifier valves — but also that it works entirely without time lag. This leads, for example, to the use of the blocking element as signal key for audio-frequency telegraphy. In this case an alternating current of a given frequency, for instance between 400 and 2400 c/sec, must be interrupted in the quick rhythm of the telegraph signals (for instance Morse signals) [2]). To do this the A.C. voltage is applied to the input terminals *1-2* of a blocking element, while to the terminals *5-6* the D.C. signals of an ordinary telegraph apparatus for double-current telegraphy (*i.e.* in which the D.C. is not switched on and off, but reversed in polarity) are applied with the correct polarity. The oscillograms in *fig. 4* show the resulting appearance of the A.C. impulses transmitted. Due to the lack of inertia in the functioning of the blocking element no distortions of the telegraph signal occur even at high signalling speeds. Furthermore it may be seen that thanks to the balanced connections of fig. 2 the controlling D.C. voltage impulses themselves do not become observable at the output: due to the completely symmetrical connections they always cause equal and opposite currents in the two halves of the transformer T_2, so that the output voltages hereby induced compensate each other.

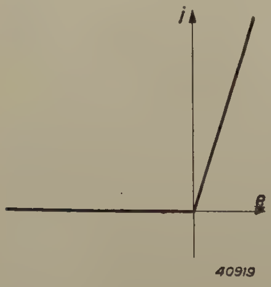

Fig. 3. Idealized characteristic of a rectifier valve. In the blocking direction, *i.e.* for negative voltage *e*, the current *i* is always zero, thus the resistance infinite; in the transmitting direction the resistance has a small constant value.

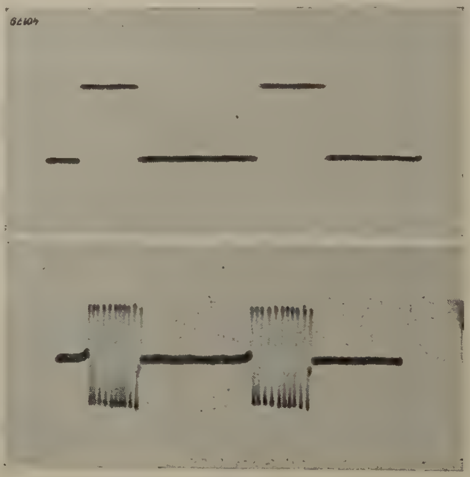

Fig. 4. Oscillograms of telegraph signals in audio-frequency telegraphy. Above: the controlling D.C. voltage impulses; below: the A.C. voltage impulses obtained at the output of the blocking element.

The blocking element as modulator

The blocking connections reproduced in fig. 2 and discussed above can now be used as a modulator without any alterations, when the low-frequency speech currents are applied to the input terminals *1-2* and the carrier wave on which the speech vibrations are to be modulated is applied to the terminals *5-6*. The fact that the desired side bands actually appear on the output terminals may be explained as follows.

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[2]) The advantages of this system over ordinary D.C. telegraphy, where a direct current is interrupted or reversed, consist in the facts that the signals can easily be transmitted over long distances and that by the application of alternating currents with different frequencies in combination with band filters different telegrams can be sent simultaneously over the same line (thus a "carrier-wave telegraphy", entirely analogous to carrier-wave telephony except for the much smaller intervals between carrier waves).

The carrier-voltage, which may have an angular frequency of p, will alternately open and close the blocking element due to the periodical reversal of sign. Let us now suppose that a sinusoidal voltage $Q \cos qt$ of low frequency acts on the input terminals (*fig. 5a*), and that

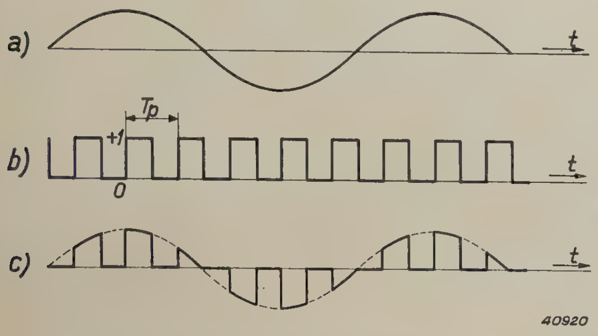

Fig. 5. At the input of the blocking connections a low-frequency A.C. voltage is applied (curve *a*). On the terminals *5-6* a much higher A.C. voltage acts with a higher frequency (carrier wave, period T_p), so that the blocking element is opened and closed periodically ("transmission") according to curve *b*). In this way an output voltage according to curve *c* is obtained.

Q is so small that the low-frequency voltage has no effect on the opening and closing of the blocking element. The blocking element then transmits only in the positive halves of the carrier wave, and thus the output voltage has the appearance shown in fig. 5*c*. The equation of this output voltage is found by multiplying the function $Q \cos qt$ by the equation of the block-form curve 5*b*, which in a Fourier series is as follows:

$$y = \frac{2}{\pi}\left(\frac{\pi}{4} + \sin pt + \frac{1}{3}\sin 3pt + \frac{1}{5}\sin 5pt + \dots\right).$$

The equation of the output voltage thus becomes

$$e_0 = \frac{Q}{2}\cos qt + \frac{Q}{\pi}\sin(p-q)t + \frac{Q}{\pi}\sin(p+q)t +$$
$$+ \frac{Q}{3\pi}\sin(3p-q)t + \frac{Q}{3\pi}\sin(3p+q)t +$$
$$+ \frac{Q}{5\pi}\sin(5p-q)t + \frac{Q}{5\pi}\sin(5p+q)t + \dots \quad (1)$$

In the output voltage the vibrations with the angular frequencies $p-q$ and $p+q$ are seen to occur. Further consideration shows that this also holds when a complex of vibrations of different frequencies q_1, q_2, ... is fed to the input. In particular, therefore, upon the application of speech vibrations which occupy a whole band of frequencies q, two bands of the frequencies $p-q$ and $p+q$, respectively, which are the desired side bands, are obtained at the output.

At the same time it is evident that upon the presence of one frequency q at the input, in addition to the side-band frequencies $p-q$ and $p+q$ various other undesired frequencies occur in the output signal, namely the frequency q itself and, as by-products of the modulation, the side bands of higher harmonics of the carrier: $3p \pm q$, $5p \pm q$, ... These fall within the frequency band of another telephone channel and there cause cross-talk; they must therefore, like the one of the two side bands $p+q$ and $p-q$ which is not wanted, be suppressed by the transmitting-band filter (see fig. 1) following the modulator. This is especially true for the frequencies $3p \pm q$ which are only a factor 3 (*i.e.* 20 log 3 $\approx$ 10 db) weaker than the desired side band, and for frequency q which is a factor $\pi/2$ (*i.e.* about 4 db) stronger.

As in the case of the controlling D.C. voltage in the blocking element, the carrier itself does not appear at the output thanks to the balanced connections. This is important when, as is customary, it is desirable not to transmit the carrier wave itself over the line for the sake of keeping the load on the common repeaters for all channels as small as possible. The same carrier-frequency must then be added at the receiving end for the demodulation.

Modulator with double push-pull connections

If the efficiency of the connections of fig. 2 used as modulator is considered, the result is not very satisfactory. When, as has been done in equation (1), we assume the valve resistance in the transmitting direction to be equal to zero, the energy ratio of one of the side bands to the input signal amounts, theoretically, to: $(Q/\pi)^2/Q^2 = 1/\pi^2$, *i.e.* a difference of about 10 db.

A higher efficiency is obtained when the single push-pull connections of fig. 2, which are given again in *fig. 6a*, are elaborated into the double push-pull connections of fig. 6*b*. These consist of two similar parts, the first of which contains the valves *a* and *b*, the second the valves *c* and *d*. If the crossing point in the second part is considered not to be there, so that the two parts differ only in the direction of the valves, one part would give an output voltage according to *fig. 7a* and the other an output voltage according to fig. 7*b*. Upon the addition which takes place in the secondary winding of the output transformer T_2 these voltages would give the low-frequency vibration unaltered and nothing else, which is not the intention. By crossing the connections from *c* and *d* to T_2 as indicated

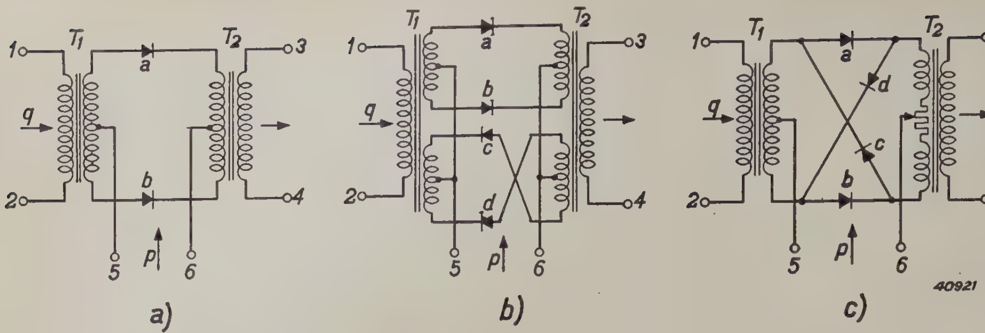

Fig. 6. *a*) Modulation with single push-pull connections (identical to the blocking connections of fig. 2).
b) Modulator with double push-pull connections.
c) Ring modulator (so called because the four valves are actually connected in a ring one behind the other).

in fig. 6*b*, however, the sign of the output voltage of fig. 7*b* is reversed, and upon addition the voltage represented in fig. 7*c* results. This voltage is the product of the low frequency vibration $Q \cos qt$ and the block-shaped curve of *fig. 8*. If we again write the Fourier series for the latter, which is

$$y = \frac{4}{\pi}\left(\sin pt + \frac{1}{3}\sin 3pt + \frac{1}{5}\sin 5pt + \dots\right),$$

and multiply this by $Q \cos qt$, after working out the equation for the output voltage we obtain

$$\begin{aligned} e_0 = \frac{2Q}{\pi}\Bigl\{ & (\sin(p-q)t + \sin(p+q)t + \frac{1}{3}\sin(3p-q)t + \\ & + \frac{1}{3}\sin(3(p+q)t + \frac{1}{5}\sin(5p-q)t + \dots\Bigr\}. \end{aligned} \quad (2)$$

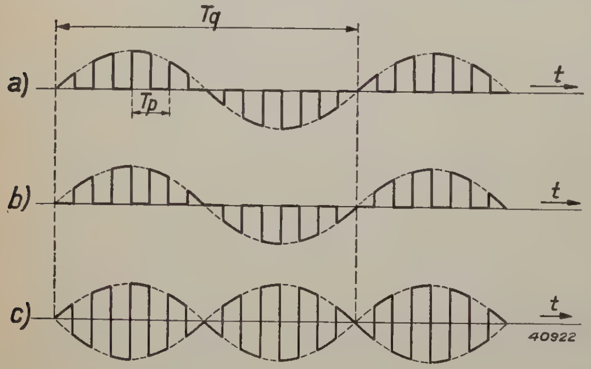

Fig. 7. *a*) Output voltage e_{ab} of the upper part of the double push-pull connections of fig. 6*b* (T_p period of the carrier wave, T_q period of the input voltage).
b) Output voltage e_{cd} of the lower part without the crossing.
c) Output voltage $e_o = e_{ab} - e_{cd}$ of the whole.

The action of the double modulator connections, according to this formula, is in the main similar to that of the single connections of fig. 6*a*, except that the undesired low-frequency component has disappeared from the output signal, while the energy ratio of one of the side bands to the input signal is improved to $(2Q/\pi)^2/Q^2 = 4/\pi^2$, *i.e.* a difference of only 4 db. Compared with the single connections, therefore, the efficiency is a factor 4 higher, since the effective signal has become 6 db stronger with the same input voltage [3]).

The connections of fig. 6*b* can still be simplified to those of fig. 6*c*, the so-called ring-modulator, which is often used. This modulator is formed by superposing the two parts of 6*b*. It is easy to see that no change occurs in the functioning of the whole, since the superposed points of the two parts always have the same potential.

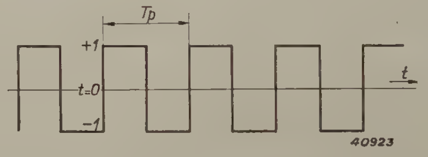

Fig. 8. Variation of the transmission of the double push-pull connections as a function of the time. T_p period of the carrier wave.

More detailed consideration of the action of the modulator

In the foregoing it has all along been assumed that the passage of the valves from the blocking state to the transmitting state and *vice versa* was controlled exclusively by the carrier wave. Actually it is not the carrier-voltage alone which is responsible for this, but the sum of the carrier and low-frequency voltages acting on each valve. Although the amplitude of the carrier voltage is much larger than that of the low-frequency voltage, the latter, depending upon its momentary value, will also contribute its bit by causing the valve to function slightly sooner or later. The output voltage will therefore not have exactly the form shown in fig. 5*c* (or 7*c*), but the zero points in the curve will sometimes be shifted slightly to the left or to the right.

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[3]) In practice in both cases the loss is further increased by about 2 db, which may be ascribed to the losses in the valves and in the transformers.

Although it is clear that this effect will cause the occurrence of new undesired components in the output signal, this cannot immediately be explained with the given method of representation. If it is desired to take this effect into account, it is no longer sufficient simply to consider the modulator as a high-frequency switch, but the behaviour of the voltage on each valve and the current caused thereby must be considered in more detail.

The relation sketched in fig. *3* between the current i and the voltage e on a valve can be represented by an exponential series with constant coefficients a_1, a_2 ...:

$$i = a_1e + a_2e^2 + a_4e^4 + a_4e^6 + \dots \quad (3)$$

The fact that the odd terms e^3, e^5, ... do not occur here becomes clear when the function $i(e)$ is considered to be formed by the addition of the two functions i_1 and i_2 drawn as dotted lines in *fig. 9*. The first furnishes only the linear term a_1e, the second, due to its symmetry, can only contain even powers of e.

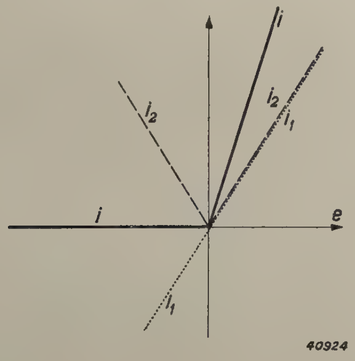

Fig. 9. The valve characteristic $i(e)$ according to fig. 2 can be regarded as the sum of the two functions $i_1(e)$ and $i_2(e)$ indicated by dotted lines.

If we now consider the simple modulator connections of fig. 6*a* we can write for the two valves *a* and *b* the following formulae:

$$\left.\begin{aligned} i_a &= a_1e_a + a_2e_a^2 + a_4e_a^4 + a_1e_a^6 + \dots,\\ i_b &= b_1e_b + b_2e_b^2 + b_4e_b^4 + b_1e_b^6 + \dots, \end{aligned}\right\} \quad (3a,\ b)$$

When, as is here assumed, the connections are completely symmetrical, and the valves are thus exactly alike, the conditions $a_1 = b_1$, $a_2 = b_2$, ... must be fulfilled.

Since i_a and i_b flow in opposite directions through the halves of the winding of transformer T_2, the output voltage e_{ab} will be proportional to the difference between i_a and i_b, thus:

$$e_{ab} \sim a_1(e_a - e_b) + a_2(e_a^2 - e_b^2) + a_4(e_a^4 - e_b^4) + \dots \quad (4)$$

In our case two A.C. voltages act on each valve, namely [4]

$$e_p = P\cos pt \text{ and } e_q = Q\cos qt, \quad \dots \dots \quad (5)$$

due respectively to the carrier-wave signal and the input signal. The sum of these voltages acts on one valve, and on the other their difference:

$$e_a = e_p + e_q \text{ and } e_b = e_p - e_q.$$

This substituted in (4) gives

$$\begin{aligned} e_{ab} \sim a_1\cdot 2e_q + a_2\cdot 4e_pe_q + a_4(8e_p^3e_q + 8e_pe_q^3) + \\ + a_6(12e_p^5e_q + 30e_p^3e_q^3 + 12e_pe_q^5) + \dots \quad (6) \end{aligned}$$

Combined with (5) this becomes:

$$\begin{aligned} e_{ab} \sim a_1\cdot 2Q\cos qt + a_2\cdot 4\,PQ\cos pt\cos qt + \\ + a_4(8P^3Q\cos^3 pt\cos qt + 8PQ^3\cos pt\cos^3 qt) + \dots (7) \end{aligned}$$

Upon working out the products cos ${}^mpt$ cos ${}^nqt$ it is found that the following frequencies occur in the output voltage:

$$\begin{array}{lll} q, & & \\ p \pm q, & p \pm 3q, & p \pm 5q, \dots \\ 3p \pm q, & 3p \pm 3q, & 3p \pm 5q, \dots \\ 5p \pm q, & 5p \pm 3q, \dots & \end{array}$$

while in the simpler discussion first given, where Q was temporarily assumed to be very small, only the frequencies in the first column of this table occurred. Indeed when Q is made so small that its higher powers can be ignored, all those terms in (7) which lead to the appearance of the new frequencies disappear.

Most of the new components can easily be suppressed by the band filters. This however, is, not true for the components with the frequencies $p \pm 3q$, $p \pm 5q$, ..., since when q is not too large they still fall in the side band to be transmitted ($p + q$ or $p - q$), and after demodulation at the receiving end they are heard as third and fifth harmonics, respectively, of the original signal. They thus cause a distortion of the speech. This distortion remains small when the low-frequency input voltage $e_q = Q\cos qt$ of the modulator is kept sufficiently small. The frequency $p \pm 3q$ for instance is due to the term a_4. $8\,PQ^3\cos pt\cos^3 qt$ in equation (7), whose magnitude rapidly falls with decreasing value of Q. By making the input voltage no larger than 20 to 30 percent of the carrier-voltage the distortion can be limited to less than 2 percent.

Formulae (6) and (7) are valid for the single push-pull connections (fig. 6*a*). If we now pass on to the double push-pull connections (fig. 6*b*) or the ring modulator (fig. 6c) the output voltage can be found as before by adding the output voltages e_{ab} and e_{cd} of the two parts with the correct sign. Equation (6) holds for e_{ab}, and for e_{cd} an equation which, since the valves are reversed compared with a and b, can be obtained by substituting for e_p in equation (6) — e_p and for e_q, — e_q. When this is done, except for the first term, e_{cd} is found to be identical to e_{ab}, since in all the terms in ${e_p}^m {e_q}^n$ the sum $m+n$ is even; only the first term $2\,a_1 e_q$ has the opposite sign. Thus upon addition this term disappears while all the other terms are simply doubled. This agrees completely with the result of the simplified discussion first given: by the doubling of the push-pull connections the low-frequency component is suppressed and the efficiency of the modulator is increased by a factor 4.

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[4] Actually other voltages also act on the valve due to the reaction of the very output voltage to be calculated. We shall disregard the reaction here, since it makes the calculations very complicated without appreciably affecting the result.

Valve characteristics which are not straight

The double push-pull connections however, have, still another important advantage which appears when, instead of the simple valve characteristic (fig. 3) assumed, the actual characteristics of the valves in practical use are used as a basis of the calculation. In general these characteristics deviate considerably from the straight type sketched in fig. 3. In *fig. 10* for instance the characteristic is given in the blocking and transmitting directions of a selenium valve 5) as used by Philips in modulators for carrier-telephony, while in *fig. 11* the transmission characteristic is drawn for a still larger range of currents and voltages.

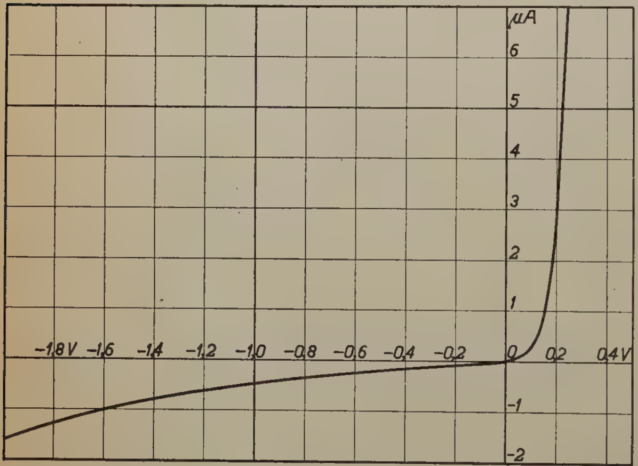

Fig. 10. Characteristic of a selenium valve as used for modulators.

The relation between the current i and the voltage e given by such an arbitrarily curved characteristic can be represented by a series quite analogous to equation (3), in which, however, all the odd powers of e must also occur:

$$i = a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_1 e^5 + \dots \quad (8)$$

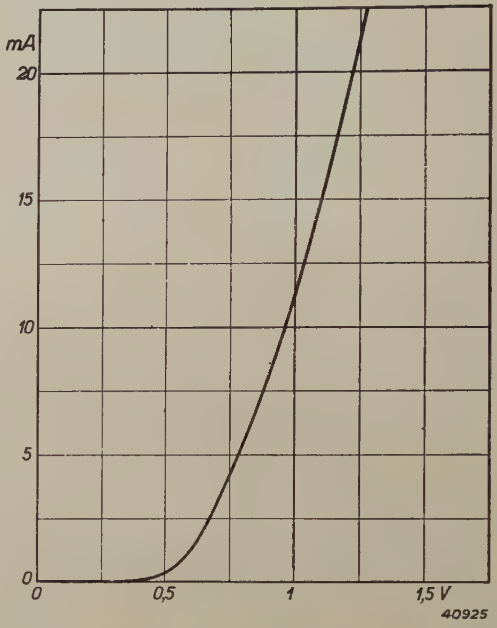

Fig. 11. Transmission region of the same characteristic as in fig. 10, but drawn on a smaller scale, so that the behaviour at the voltages actually used (order of magnitude 1 V) may be seen. The deviation from the idealized characteristic according to fig. 3 is considerable.

With this the calculation of the output voltage can be carried out in exactly the same way as above, and one then finds for the single push-pull connections instead of equation (6):

$$e_{ab} \sim a_1 \cdot 2e_q + a_2 \cdot 4\, e_p e_q + a_3\,(6\, {e_p}^2 e_q + 2{e_q}^3) + a_4\,(8\, {e_p}^3 e_q + 8\, e_p {e_q}^3) + \dots \quad (9)$$

The difference between this and equation (6) is that now terms in ${e_p}^m {e_q}^n$ also occur in which $m+n$ is *odd*. Because of this, as is found upon substitution of (5) and further working out, in the output signal there occur not only the side bands of the odd harmonics of the carrier-wave, *i.e.* $3p \pm q$, $5p \pm q$, etc., but also the side bands of the even harmonics, *i.e.* $2p \pm q$, $4p \pm q$, etc.

In *table I* (fifth column) this result is placed beside the frequency spectra found in the fore-

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5) See W. Ch. van Geel, Blocking-layer rectifiers, Philips Techn. Rev. 4, 100, 1939.

6) The even harmonics of the input frequency q are always missing, even in the side bands of the carrier wave and of the harmonics of the carrier wave. This is due to the balance of the connections of fig. 6a, just as in push-pull amplifiers, where the even harmonics are also found to disappear.

going, for the sake of comparison. Especially the components $2p \pm q$ (and $2p \pm 3q$, $2p \pm 5q$, ...) are a very undesirable "gain", since in order to suppress them new and more rigorous requirements are made of the transmitting-band filters.

Table I

"Straight" characteristic				Curved characteristic	
$Q \ll P$		$Q \approx P$		$Q \approx P$	
Single push-pull	Double push-pull	Single push-pull	Double push-pull	Single push-pull	Double push-pull
q		q		q $3q$ $5q$ ...	
$p \pm q$	$p \pm q$	$p \pm q$ $p \pm 3q$ ...	$p \pm q$ $p \pm 3q$ ...	$p \pm q$ $p \pm 3q$ ...	$p \pm q$ $p \pm 3q$ ...
				$2p \pm q$ $2p \pm 3q$ ...	
$3p \pm q$	$3p \pm q$	$3p \pm q$ $3p \pm 3q$ ...	$3p \pm q$ $3p \pm 3q$ ...	$3p \pm q$ $3p \pm 3q$ ...	$3p \pm q$ $3p \pm 3q$ ...
				$4p \pm q$ $4p \pm 3q$ ...	
$5p \pm q$	$5p \pm q$	$5p \pm q$ $5p \pm 3q$ ...	$5p \pm q$ $5p \pm 3q$ ...	$5p \pm q$ $5p \pm 3q$ ...	$5p \pm q$ $5p \pm 3q$ ...

If we now again consider the double push-pull connections and calculate the output voltage by writing out e_{ab} and e_{cd} and adding them, it will be seen that upon substituting $-e_p$ for e_p and $-e_q$ for e_q in equation (9), it is just the new terms with odd values of $m + n$ which change their signs and thus disappear upon addition. By the employment of the double push-pull connections, therefore, the disadvantage of the curved instead of straight valve characteristic is eliminated, as far as the number of components in the output signal is concerned. This may clearly be seen from the table. This advantage, together with that of the higher efficiency, leads to the common use of the double push-pull connections, in the form of the ring modulator or not as the case may be.

Practical construction of the modulators

In the practical construction of the modulators the most important point is the choice of the valves. From the detailed considerations of the action of the modulator which were based upon equations (3) and (8) for the valve characteristics, it has been made clear that it is actually not the "valve" action of the circuit elements in question, which action was emphasized in the initial general discussion, which is essential, but in general the non-linearity of the relation between current and voltage. It is especially the square term a_2e^2 in the exponential series which describes this relation (equation 3 or 8) which causes the apparence of the desired side bands $p \pm q$. Every non-linear element which possesses a characteristic with this term is therefore in principle suitable for the modulator.

In the early days of the development of carrier-wave telephony (around 1920) electronic valves (triodes for example), such as those used in radio technology, were used as non-linear elements. During the last ten years, however, in the modulators as well as in other parts of the carrier-system where non-linear elements are needed, the electronic valves have been replaced by blocking-layer cells (blocking-layer rectifier valves), since the latter offer important practical advantages:

1) They possess no electrodes which require separate supply like the cathode and anode of the electronic valve. The connections and assembly therefore become simpler, the supply apparatus of the whole installation becomes smaller and the installation and running costs thus become lower.
2) The blocking-layer cells occupy very little space. This is demonstrated clearly in the photograph of *fig. 12*, where a selenium cell (selenium rectifier valve) developed by Philips for the purposes of telephony is shown together with a unit of four such cells intended for a modulator with double push-pull connections [7]). In *fig. 13* it may be seen how the unit is mounted in a complete modulator.

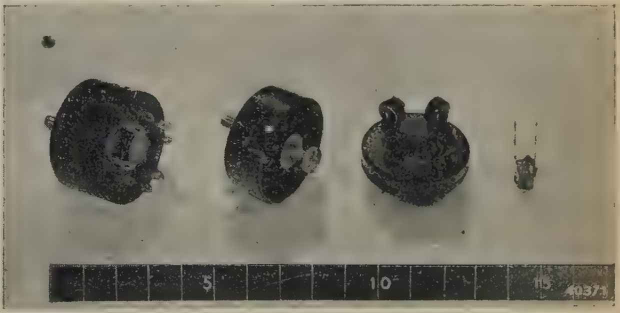

Fig. 12. On the right a single selenium cell as made by Philips for general purposes of telephony. On the left a "unit" of four cells for a modulator, in the middle the same unit with the cover removed. The centimer scale shows the small dimensions of the cell and the unit.

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[7]) The small dimensions were made possible by the fact that these cells only need to carry very small currents, in contrast to selenium cells which are used for instance in supply or charging rectifiers. See in this connection D. M. Duinker, Philips techn. Rev. 5, 199, 1940.

3) The life of the blocking-layer cells with the light loading here involved is very long, so that the cells need not be placed at easily accessible spots, and greater freedom is thus obtained in the construction of the apparatus.

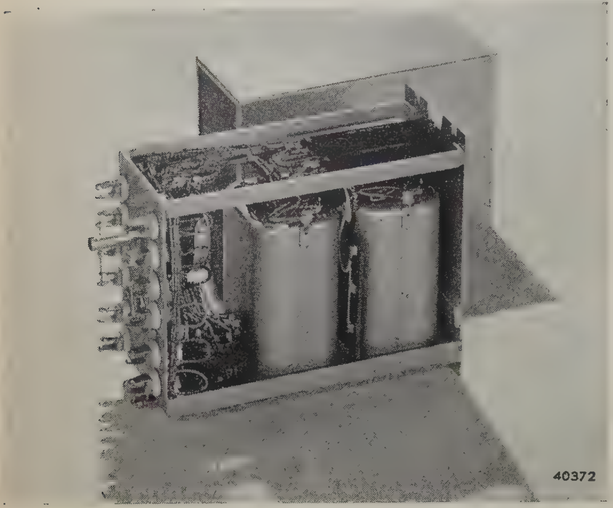

Fig. 13. Modulator of a carrier-telephone installation developed by Philips. The largest part of the chassis is occupied by two transformers. To the left below is the unit with the valves, above it a small potentiometer for balancing (see below).

In the foregoing complete symmetry of the modulator connections has been assumed: the two or four blocking-layer cells in the modulator had exactly the same characteristic, the halves of the windings of the transformers were exactly the same, etc. Actually this will never be precisely the case. In particular the characteristics of the blocking-layer valves, an example of which is given in fig. 11, always exhibit some difference; upon comparison of random examples the characteristics may even be quite different. The result of the dissymmetries hereby introduced is that in the calculation of the output signal given above equation (4) is already no longer valid, since $a_1 \neq b_1$, $a_2 \neq b_2$, etc., so that for the single (equation 6) as well as for the double push-pull connections terms in e_p, e^2_p, e^3_p, e^2_q, $e_p e_q^2$, etc. still appear in the output voltage. Because of this, more or less intense components with the frequencies p (the carrier), $2p$, $3p$, $2q$, $p \pm 2q$, etc. also occur as products of the modulation. The oscillogram of *fig. 14* shows the effect of these on the form of the output signal.

Among these extra modulation products the carrier wave p could only with much difficulty be suppressed by the filters, while this is even fundamentally impossible for the frequencies $p \pm 2q$, $p \pm 4q$, etc. (as in the case of the components $p \pm 3q$, $p \pm 5q$, ... mentioned above), since they may fall within the desired side band itself. Now in order to keep these terms, and especially the so-called carrier-leak, small, the dissymmetries of the modulator must be limited as far as possible. For that purpose in the first place great care is devoted during manufacture not only to obtaining the greatest possible symmetry in the construction of the transformers, but also to selecting two or four valves as nearly as possible alike. Account must also be taken of the requirement that sufficient symmetry is maintained during use for a reasonable time. The dependence of the valve characteristic on the temperature and the small changes in the valve properties with time (ageing) must therefore be as nearly as possible identical for the four valves to be combined.

In the second place a small potentiometer may be connected between the halves of the windings of the primary of the transformer T_2, as was already indicated in the diagram of fig. 6c. By this means slight residual dissymmetries of the valves and transformers can be balanced, at least as long as the dissymmetries lie in the real part of the impedances. Since the blocking-layer valves possess a certain capacity and the transformers a certain leakage self-induction, which may also cause some dissymmetry, a complex resistance must actually be used for the balancing, for example a potentiometer in parallel with a differential condenser. In most cases, however, the carrier-leak can be adjusted to a sufficiently small value even without the last-mentioned element.

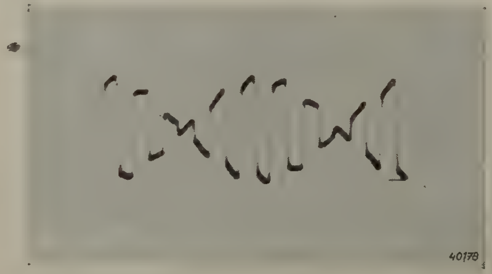

Fig. 14. Oscillogram of the output voltage of a modulator in double push-pull connection. The carrier-frequency here amounted to 6 000 c/sec, the low-frequency input voltage had a frequency of 600 c/sec. The deviations of the curve from the ideal form are to be ascribed mainly to dissymmetries in the modulator connections.

In conclusion a few words about the demodulator, which serves to restore the frequency bands arrriving at the receiving end to their original frequency region. In principle it is similar to the modulator and the same apparatus can be used. If, for example, we apply to the modulator a signal with the frequency $p + q$ and a carrier wave with the frequency p, among other voltages those with the sum and difference frequency $2p + q$ and q will occur at the output. Furthermore a number of undesired modulation products also occur again, which we can immediately derive from table I by replacing q by $p+q$. Of all the output components only those with the frequency q are desired, the others being suppressed as far as possible in the low-pass filters following the demodulator.

ON THE POROSITY OF WELDS

by J. TER BERG [1]). **621.791.056**

In electric arc welding the weld is sometimes found to be porous. This porosity can be caused by the presence of sulphur. Certain welding rods are very sensitive to sulphur, while others are insensitive to it. In this article some experiments are described which illustrate the importance of the sulphur content of the material being welded on the resulting weld. In particular these experiments show that the non-uniformity of the distribution of sulphur in the work piece can affect the results obtained. It is also shown that it is advisable to use rods which are insensitive to sulphur.

One of the most important problems in welding technique is that of the measures which should be taken to obtain a weld with good mechanical properties. Especially in electric arc welding with coated electrodes it occasionally occurs that the weld is porous, which means a considerable decrease in the mechanical strength. It is clear that the occurrence of such a phenomenon or even the possibility of its occurrence is a strong impediment to the application of arc welding.

In the course of years many attempts have been made to discover the causes of the porosity. A successful result was only obtained when experiments were carried out in this laboratory with the object of investigating the relation between porosity and the presence of sulphur.

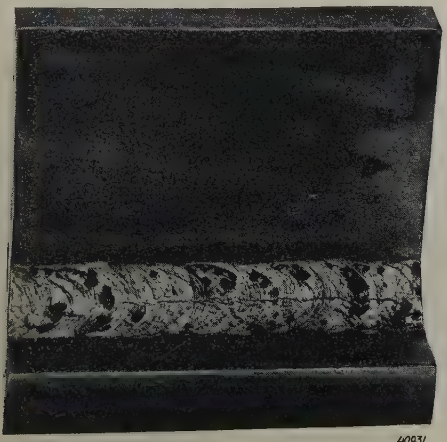
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Fig. 1. Fillet weld made with a sulphur-sensitive electrode on a material containing considerable sulphur. The bead is porous and contains pocks and is, moreover, cracked.

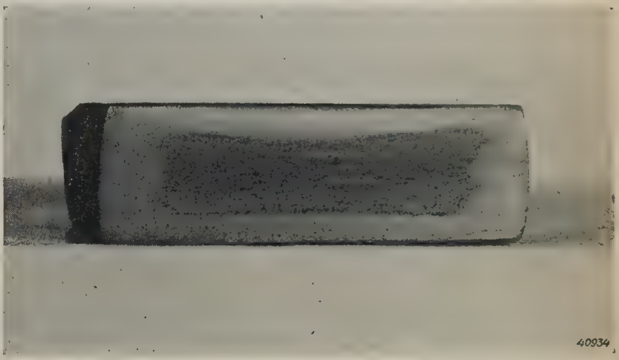
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Fig. 2. Rolled and etched strip with sulphur segregation. This may clearly be seen on the polished surface.

For this purpose the element in question was expressely added to a large number of different kinds of welding rods. The addition of sulphur can be realized in a simple way by immersing the coated electrode in a saturated solution of sodium sulphate for a certain time and then drying it.

These experiments led to the surprising result that in the case of certain kinds of rods a very small amount of sulphur [2]) was able to cause the porosity [3]) under consideration, while with other types even a large percentage of sulphur had no effect on the soundness of the weld. We shall call the first type sulphur-sensitive electrodes and the second type sulphur-insensitive rods. This sensitivity or insensitivity to sulphur is due to certain specific properties of the coating.

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[1]) Partially in collaboration with Ir. J. Sack †.

[2]) The elements following sulphur in the periodic system, selenium and tellurium, exhibit this specific effect of producing porosity to an even greater degree. Phosphorus, however, which, is often classed with sulphur as far as its effect on metals is concerned, does not have this property.

[3]) By porosity in this connection must also be understood the phenomenon where the surface of the weld is covered with small depressions, usually called pock-marked.

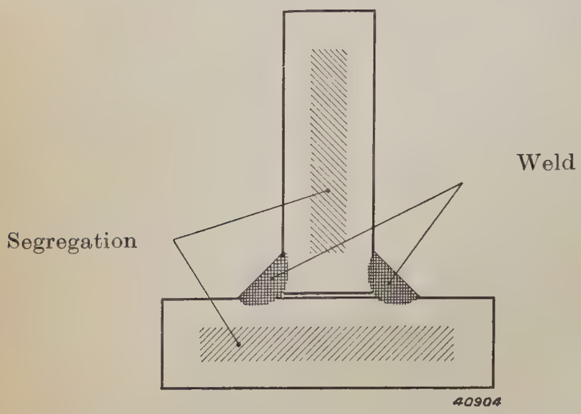

Fig. 3. Diagram of the cross section of a fillet weld. The fused zone penetrates only about 2 mm into the material and need not touch the internal segregation of sulphur.

A practical conclusion from the observations described is that the certainty of obtaining a sound weld with a sulphur-sensitive rod can be increased by choosing the sulphur content of core wire and coating very low, for instance lower than 0.015 percent in both cases. It is, however, also possible that the material to be welded contains so much sulphur that it is impossible to prevent porosity by this means. In that case it is necessary to use sulphur-insensitive electrodes. It will be clear that the use of sulphur-insensitive electrodes is far preferable for quality work, since then there need be no fear of an unfavourable composition of the material as far as the sulphur is concerned.

An example of an electrode which is insensitive to sulphur is the Philips 55, which has already been described in this periodical. [4]) Even free cutting steels which contain about 0.25 percent of sulphur can be welded with this rod without porosity.

In the following we shall describe several experiments which demonstrate the detrimental effect of sulphur upon the use of sulphur-sensitive electrodes, and which at the same time also give an idea of some phenomena which sometimes occur in welding practice. In this case we shall devote our attention exclusively to the sulphur content of the material to be welded.

In *fig. 1* a fillet weld is shown which results from the welding of material containing much sulphur with a sulphur-sensitive electrode. In addition to holes and pocks, cracking of the weld may also occur, as in this case. The cracking will not be discussed in this article, however.

Remarkably enough, no correlation could at first be found between the degree of porosity and the sulphur content of the work-piece as determined by a chemical analysis. This phenomenon could be explained, however, by taking into account the fact that the sulphur, like other impurities, is not as a rule homogeneously distributed throughout the material. It is known that impurities which lower the melting point of a metal become concentrated during the solidification mainly in the part of the metal that remains liquid for the longest time, thus in the interior of the block of metal. This accumulation of impurities continues to exist even after the rolling of the block to strip or other form and can be made visible by polishing and etching. In *Fig. 2* such segregations of sulphur in the interior of the strip are clearly observable. In making fillet welds in which only a relatively thin layer of the work-piece is fused (see *fig. 3*), the sulphur may not cause any difficulty and much better results may be obtained than would be expected from chemical analysis, which

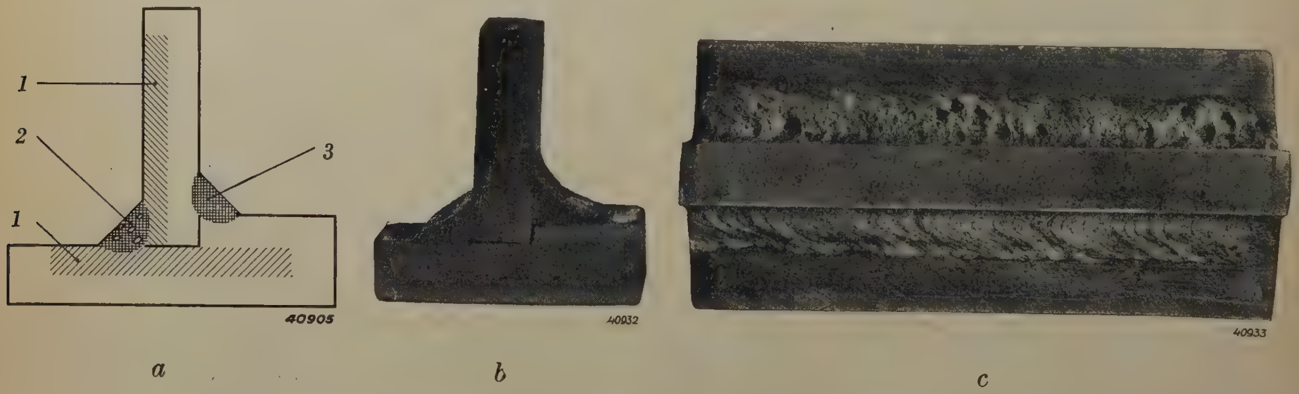

Fig. 4. Fillet weld with a sulphur-sensitive rod in which on one side of the strips the upper layer was planed off until the segregation was reached. a) Diagram, 1 segregations, 2 porous weld, 3 sound weld. b) Cross section of the actual weld, c) view of weld from above. The difference in quality between the two welds is clearly visible.

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[4]) P. C. van der Willigen, Philips Techn. Rev. 6, 97, 1941.

gives the average sulphur content. Thus in judging the weldability of a kind of steel attention must be paid not only to the average sulphur content but also to the distribution of this element [5]).

The correctness of the above conclusion can be demonstrated in a simple way by cutting away part of the surface of two strips until the sulphur-containing core is bared, in the manner ilustrated in *fig. 4a*. In laying a double fillet weld with a sulphur-sensitive electrode it is now found that one weld may be sound while the other, which penetrates into the segregation, exhibits many holes and is pock-marked. Fig. 4*b* shows an etched cross section of such a piece of work ; in the left-hand weld one of the holes may be seen on the surface. Fig. 4*c*, a view from above, clearly shows the difference in quality between the two welds.

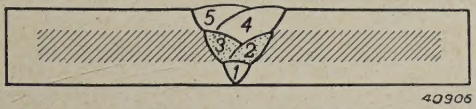

Fig. 5. Diagram of the cross section of a V-weld in a material with sulphur segregation. The beads 1, 4 and 5 are sound, the beads 2 and 3 may become porous upon the use of a sulphur sensitive electrode.

An important case where the distribution of sulphur plays a part in actual practice occurs in making a V weld as represented in *fig. 5*. Upon welding with a sulphur-sensitive rod porosity may occur in the beads *2* and *3* while the other beads are sound. Such phenomena have sometimes been observed also in other types of welds, and can thus be explained as due to the non-homogeneity of the distribution of sulphur.

In conclusion we present a general remark about the weldability of iron and steel. In various countries, including the Netherlands, committees have been appointed with the object of studying this question more closely. The function of these committees consists chiefly in formulating definite requirements, primarily relating to the chemical composition, which the material to be welded must satisfy. From the foregoing, however, it is obvious that a general solution of the problem cannot be found in that way, but that account must also be taken of the distribution of the impurities in the work-piece and of the specific properties of the welding rod, like the sensitivity to sulphur discussed in this article.

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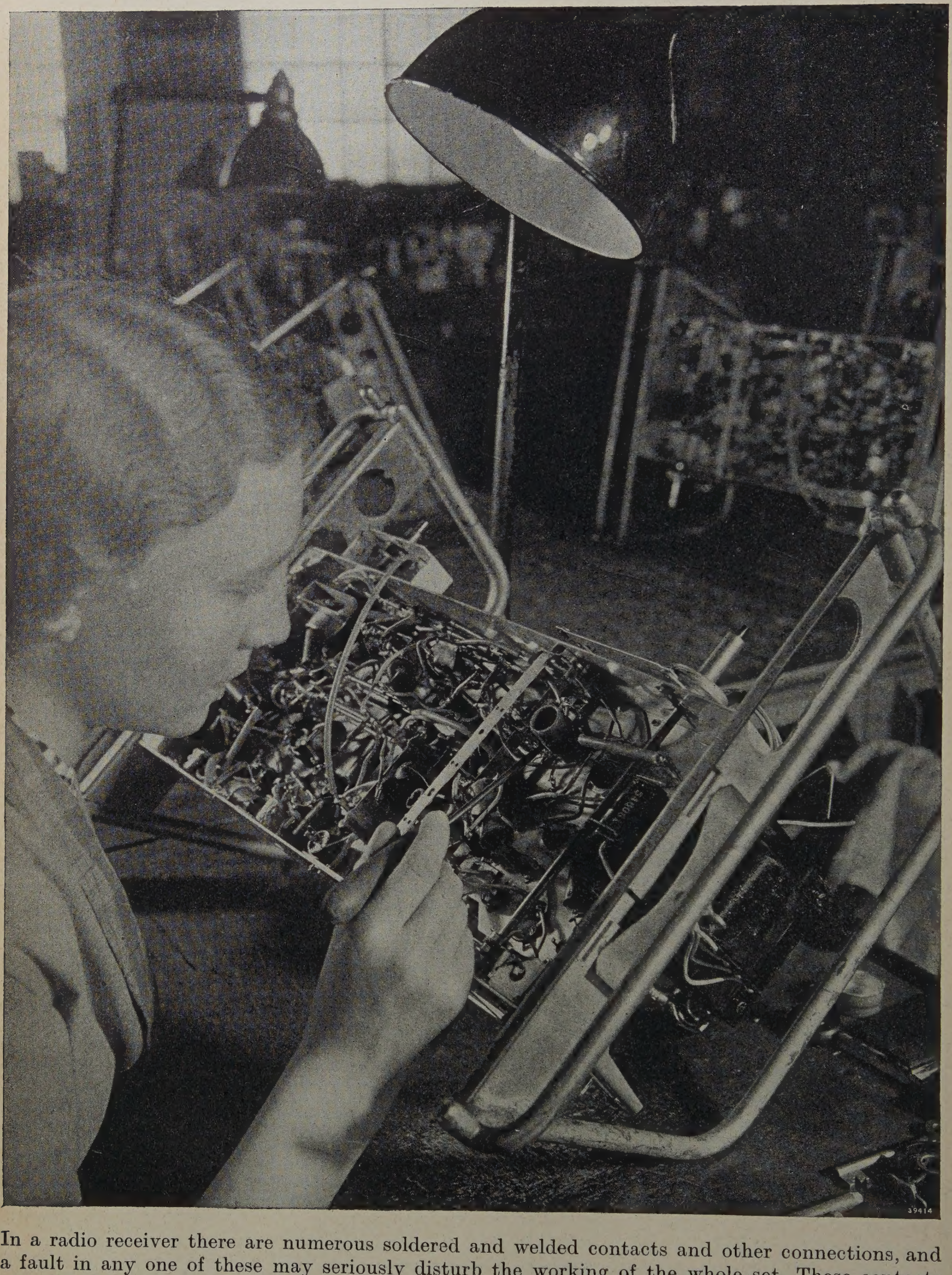
[5]) This distribution can also be made visible, for example by pressing a polished surface of the work-piece on photographic paper. Upon contact with the sulphur the white silver chloride is converted into brown silver sulphide, and a picture of the sulphur distribution is thus obtained.

THE TESTING OF CONNECTIONS IN A RADIO RECEIVING SET



In a radio receiver there are numerous soldered and welded contacts and other connections, and a fault in any one of these may seriously disturb the working of the whole set. These contacts therefore have to be subjected to several tests and although these take considerable time they cannot be dispensed with.

SUMMARY OF RECENT SCIENTIFIC PUBLICATIONS ISSUED BY N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these publications will be gladly supplied free of charge upon request to the Administration of the Natuurkundig Laboratorium, Kastanjelaan, Eindhoven. Reprints of any publications marked with an asterik, however, are not available in sufficient number for distribution.

1561: J. L. Snoek: Effect of small quantities of carbon and nitrogen on the elastic and plastic properties of iron (Physica **8**, 711-733, July 1941).

The elastic after-effect phenomena both in pure iron and in commercial iron are discussed in so far as they are caused by nitrogen and carbon in solid solution. In all the materials examined, for so far as they are cubic body centered, the elastic after-effect appears to be of the same nature. At the temperatures examined the after-effect can be described with sufficient accuracy by one single relaxation time, which agrees with the magnetically determined value. As function of the measuring temperature the damping shows a maximum. This all refers to annealed materials. When they are cold worked this maximum disappears and at higher temperatures another maximum occurs. This latter maximum is explained as being a consequence of the diffusion damping, whilst for the first maximum an explanation is given which differs somewhat from what has previously been assumed to apply.

1562: J. L. Snoek: On the decarburisation of steel and related questions (Physica **8**, 734-744, July 1941).

The already known ferritic bands with a sharp boundary, arising from the decarburisation of steel, are attributed to the high rate of diffusion of carbon in *α* iron. This phenomenon is considered from the same point of view as the low affinity of carbon to *α* iron and the known extremely low degree of solubility. In all these respects there is a great similiarity between carbon and nitrogen. Also the plastic behaviour of iron is very characteristically influenced by very small quantities of carbon or nitrogen.

1563: J. L. Snoek: A mechanical counterpart to the Rayleigh law of ferromagnetic hysteresis (Physica **8**, 745-747, July 1941).

Measurements have been made to determine in how far the hysteresis damping of an annealed nickel wire is dependent upon the amplitude. As expected, it proves to increase linearly with amplitude. In a magnetic field of 300 Oersted such an increase disappears entirely and the damping becomes independent of amplitude. The hysteresis part of the damping proves to be rather strongly dependent upon temperature.

1564: J. F. H. Custers and G. W. Rathenau: Recrystallization in rolled nickel-iron (Physica **8**, 759-770, July 1941).

Rolled sheets of polycrystalline aluminium recrystallize in the deformation texture, whereas sheets of nickel-iron and copper recrystallize in cube orientation. This has been explained by the fact that crystals in cube orientation are found in the rolling texture of copper and nickel-iron, not in this texture of aluminium. A difference of the slip mechanism is held responsible for the difference in deformation texture. Small additions of some elements prevent nickel-iron and copper from recrystallizing in cube orientation. It is shown that contaminations of nickel-iron with phosphorus must be considered to affect not the slip mechanism but the process of recrystallization itself, since cube germs are present in the rolling texture of the contaminated samples. The recrystallization texture of pure nickel-iron itself depends on temperature. A study of the temperature-dependence with the aid of microstructures shows that after recrystallization at about 900-1000° C the cube crystals contain twins, which vanish at still higher temperatures. On recrystallizing nickel-iron and copper at high temperatures the cube orientation becomes absolutely dominating, although the majority of the deformed crystals had different orientations. By etching nickel-iron strips to small thickness before recrystallization at high temperatures, it is shown that the recrystallization texture in cube orientation gives way for an ideal rolling texture as the thickness of the sample decreases. An explanation is put forward geometrically.

1565: J. F. H. Custers: Uber die (111)-Reflexe im gewalzten und rekristallisierten Nickeleisen (111 Reflexes in rolled and recrystallised nickel-iron) (Physica **8**, 771-788, July 1941).

The rolling and recrystallization textures of a nickel iron with 48% nickel have been examined with X-rays to investigate the so-called (111) reflexions caused by the presence of crystal grains in the annealed strip, which differ from the dominating cube orientation. Part of the crystal grains are already in cube orientation in the rolled strip. The small crystals, which are not in cube orientation after heating at a temperature below 900° C, cannot be ascribed to twin formation, nor to a superposition of (111) and (112) orientations, which occur most in the rolling texture. The formal definition of these so-called Z grains, as twins turned 8° around an axis perpendicular to the twin plane (111), fits entirely with the experimental findings. In the recrystallization texture of very thin strips of nickel iron there are many of these Z grains. After recrystallization at 1100° C, however, one finds twins having an octahedral plane in common with the cube orientation. With the aid of the abovementioned Z texture one can generally well understand the rolling texture of nickel iron. Both the rolling texture and the recrystallization texture differ in the internal and in the external layers. This explains in part the connection between rolling texture and non-cubic orientation of crystal grains after recrystallization. After recrystallization the cube orientation is noticeably sharper in an external layer than in an internal one. Further, the degree of perfection depends also upon the thickness of the material; in extremely thin strips the cube orientation after recrystallization is very imperfect.

1566: W. de Groot: The decay of the luminescence of zinc-sulphide-phosphors excited by X-rays (Physica, **8**, 789-795, July 1941).

The manner in which the luminescence of zinc-cadmium-sulphide decreases with the time after irradiation with X-rays follows a hyperbolical law; the intensity of the luminescence proves to be inversely proportional to the square of $1 + t/\Theta$, where the time constant $\Theta = 3 \cdot 10^{-4}$ sec. This is entirely independent of the intensity of the previous X-ray irradiation, which means that the individual quanta of X-rays of 50 kV each excite a small volume of the crystal independently of each other. By using a constant already found in the law of the bimolecular reaction for the recombination of "free electrons" and "holes" in the crystal lattice, one finds $6 \cdot 10^{-15}$ cm^3 as the upper limit for the total volume of an electron cloud released by a single X-ray quantum. In willemite and cadmium the luminescence appears to decrease exponentially with time with a decay period of about 0.005 sec.

1567: J. L. Meyering: Some relations concerning the compressibility of the solid elements (Physica **8**, 796-804, July 1941).

For various metals the relation between atomic volume and compressibility is compared with: 1) heat of sublimation, 2) the lattice energy, *i.e.* the sum of the heat of sublimation and the ionisation heat, and 3) the melting point. An expression given by Bomke has been verified. The parallelism proves to be best in the first and third cases; the given relations can then be applied also to non-metals.

1568: J. H. Gisolf, W. de Groot and F. A. Kröger: The absorption spectra of zinc-sulphide and willemite (Physica **8**, 805-809, July 1941).

Contradictions in the results reached by different authors in regard to the absorption spectra of zinc-sulphide and willemite are reduced to differences in thickness of the layers examined, resulting in different spectral regions playing a preponderant role in the absorption in each different case. Some new measurements are reported for the absorption of ZnS-Cu crystals (dimensions about 30 μ) in the wavelength region between 3000 and 4000 Å.

1569: E. J. W. Verwey: Properties of suspensions, especially in non-aqueous media (Rec. trav. chim. Pays Bas **60**, 618-624, July-Aug. 1941).

The properties of suspensions of finely ground materials in various dispersion media, as a function of their degree of colloid chemical stability, are discussed. Special attention is given to unstable suspensions showing a phenomenon similar to coacervation (found with lyophilic colloids), and to stable suspensions with dilatant sediments.

Contents of Philips Transmitting News 8, No. 3, September 1941.

F. de Fremery, The electro-acoustic equipment of broadcasting studios I.

C. G. A. von Lindern, A tropic-proof radio link on ultra short waves.

K. F. Niessen, The electric field-strength as a function of the energy absorbed by the aerial.